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THE ADIRONDACK ANORTHOSITE AND ITS PROBLEMS[1]

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ABSTRACT

Bowen, Miller, and Balk have proposed theories of the origin of the Adirondack anorthosite. These theories have been discussed by many geologists. Certain aspects of their proposals are applicable to the rocks of that region. I believe that there is sufficient evidence to question whether the problems there are completely understood and solved. This paper, therefore, is a discussion of four chief theories, with the conclusion that Balk's views are the most satisfactory at the present time. There are, however, several difficulties with his postulates.

INTRODUCTION

The geology of the Adirondack pre-Cambrian is complex. Much of this complexity is due to difficulties in the field. Glacial drift obscures a great deal and it is difficult to push one's way through the woods, especially where forest fires have left nature's barbed-

[1] I am indebted to Dr. Robert Balk for the loan of an unpublished manuscript, which, since this was written, has appeared as follows: "Structural Geology of the Adirondack Anorthosite," *Sonderdruck aus Mineralogische und Petrographische Mitteilungen*, Bd. 41, H. 3–6, pp. 309–434. This paper will reveal the painstaking and prodigious work he has done. He has corresponded with me at some length about these problems. I desire to thank Robert S. Moehlman, a student of geology in the University of Rochester, for assisting me in these problems by discussing them both in oral and in written form. Dr. Quentin D. Singewald materially helped me by reading the manuscript and suggesting certain changes. To the Adirondack geologists I am indebted, chiefly through their publications, for their observations and conclusions. Especially I desire to express my great appreciation for the kindly encouragement, thoughtful guidance, and inspiring assistance I received from my beloved teacher, Professor James F. Kemp, whose memory I shall always cherish.

wire entanglements. But perhaps the divergent opinions of geologists, who have worked in the area, are even more disconcerting. I feel that much of the discussion pertaining to the petrogenesis of the Adirondack anorthosite is confusing even to those who have studied

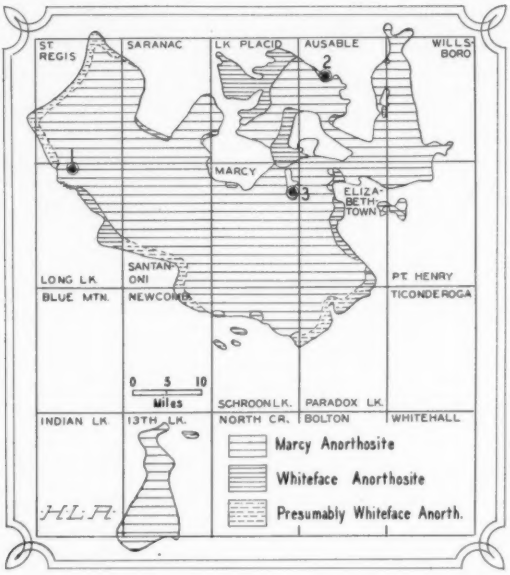

FIG. 1.—Sketch map of the Adirondack anorthosite bodies, compiled from New York State Museum geological maps in various bulletins, prepared by Cushing, Kemp, Ogilvie, Miller, and Alling. Where such maps were lacking, recourse to the old state map of Merrill was necessary. The quadrangles are named. The three numbered localities are as follows: (1) the Long Lake locality; (2) the Stickney Bridge locality; (3) the Keene Valley inlier. These localities are discussed in the text.

REFERENCES.—*St. Regis* and *Saranac* quadrangles, H. L. Alling, "Geology of the Lake Clear Region," *N.Y. State Mus. Bull. 207–8* (1919).

Lake Placid quadrangle, W. J. Miller, *N.Y. State Mus. Bull. 211–12* (1919).

Ausable quadrangle, J. F. Kemp and H. L. Alling, *N.Y. State Mus. Bull. 261* (1925).

Long Lake quadrangle, H. P. Cushing, *N.Y. State Mus. Bull. 115* (1907).

Mt. Marcy quadrangle, J. F. Kemp, *N.Y. State Mus. Bull. 229–30* (1921).

Elizabethtown and *Port Henry* quadrangles, J. F. Kemp, *N.Y. State Mus. Bull. 138* (1910).

Schroon Lake quadrangle, W. J. Miller, *N.Y. State Mus. Bull. 213–14* (1919).

Paradox Lake quadrangle, I. H. Ogilvie, *N.Y. State Mus. Bull. 96* (1905).

Thirteenth Lake quadrangle, W. J. Miller, *Amer. Jour. Sci.* (5), Vol. XVIII (1929), p. 384.

the problems there, because (1) no one geologist has seen all that there is to see, due to the extent of the area, (2) the Adirondack geologists do not agree regarding the facts, (3) the same field facts are not interpreted alike by any two geologists, and (4) there are a number of preconceived views regarding the rock units and their interrelations that undoubtedly influence their thinking. Only a psychologist can evaluate this latter point, but it is an important one.

Thus it cannot be expected that all is clear and settled about the geology of this region; it certainly is not in my own mind. There is much to be done in the area, but nevertheless the attempt will here be made to present alternative views upon the problems of the anorthosite in particular and the Adirondack pre-Cambrian in general, for it is necessary to get a large and comprehensive view as a stage-setting for the specific object of this paper: to discuss the origin of the Adirondack anorthosite.

ADIRONDACK GEOLOGY

No two geologists will set up the same geologic table. The names of the rock units even will differ and fundamental nomenclatures will be divergent. I offer the geologic tabulation as shown in Table I.

This tabulation recognizes the possibility of five major divisions. The ones usually emphasized because of bulk and readiness of distinction in the field are No. 2—Grenvillian, and No. 4—Algoman. The latter includes the anorthosite, the so-called syenite-granite "series," and certain gabbros. I am not questioning the reality of the syenite-granite "series," nor criticizing the term, but recording the fact that it is the custom of some to call the nordmarkite-quartz nordmarkite-soda granite group a "series" and thereby convey the impression that all syenites and granites of the Adirondacks belong to one group; products of one parent magma. It may be that some of them do, but the undeniable fact remains that some geologists do not think so. Likewise with the gabbros; do all of them show genetic relations to the Algoman intrusives? Some do not think so.

BOWEN'S THESIS

In 1917, Bowen[1] presented his challenging paper. His essential thesis was a dual one: (1) the Adirondack anorthosite is laccolithic

[1] N. L. Bowen, "The Problem of the Anorthosites," *Jour. Geol.*, Vol. XXV (1917), pp. 209–43.

or lens-like in form, and (2) was not molten as such, but differentiated from a gabbroic magma; the plagioclase separating from a melt by a process of differentiation-crystallization through crystal settling controlled by gravity.

The first I accept; the second conclusion I question. It may be that Bowen caught the clue of the laccolithic character from previous investigators. Daly[1] sums up the evidence for a laccolithic form of

TABLE I

GEOLOGIC TABULATION

MAJOR DIVISIONS			ROCK	OTHER TERMS
Paleozoic			Bostonite Camptonite	
PRE-CAMBRIAN	5	Keweenawan	Diabase	
	4	Algoman	Gabbro	Norite, hyperite, basic gabbros
			Granite, Syenite-granite, Syenite	Soda granite, quartz nordmarkite, laurvikite, nordmarkite
			Anorthosite	Marcy and Whiteface types
	3	Laurentian(?)	Granite, Syenite (?), Monzonites, Diorites	
	2	Grenvillian	Sediments	Various marbles, para-schists and paragneisses
	1	(?)Keewatin	Orthamphibolites	Greenstone, metagabbros, inclusions in later rocks
	And various synthetics of several ages, such as the Keene gneiss.			

the anorthosites of the world and certainly suggests the essential thesis of Bowen's view. Bowen has extended them further and in my opinion perhaps too far. Daly notes that there are only a few effusive or extrusive equivalents of the anorthosites and that inclusions are rare. He concludes that anorthosites lack batholithic stoping powers and hence are laccolithic in structure. He believes that the peculiarities of anorthosites can be explained on the basis of (1) high viscosity, or (2) a minimum amount of gaseous constituents, and (3) a thick cover.

[1] R. A. Daly, *Igneous Rocks and Their Origin* (1914), pp. 321–38.

BALK'S THESIS

Under the stimulation of Bowen's paper, Balk[1] has undertaken a prodigious piece of field work involving the measurement of the foliation of anorthosite and associated rocks of the central Adirondacks. His energy and thoroughness is to be highly commended and he deserves the hearty thanks of all the geologists interested in the problems of the Adirondacks in particular, and the origin of anorthosite in general.

Balk has made a structural survey examining the mechanical aspects of the injection of the Adirondack rocks, independent of chemical and petrographic studies. He felt that by attacking the Adirondacks anew, uninfluenced by preconceived views, new facts would come to light and more reliable conclusions would be reached.

He has drawn important conclusions, many of which will be accepted by the Adirondack geologists, while others will be questioned, others doubted, and still others denied.

His thesis is that—

1. The anorthosite, (Algoman) syenite, and (Algoman) gabbro are all consanguineous and the product of a common parent magma.

2. The foliation of these rocks was developed before the complete consolidation and is protoclastic in origin.

3. The anorthosite-syenite group is approximately contemporaneous with the lack of any appreciable time difference in the strict sense of the term.

4. The anorthosite originated by the aggregation of labradorite crystals as suggested by Bowen, but not, however, controlled by gravity. Forces of pressure flowage were more dominant than that of gravity. Hence Balk departs from Bowen's idea regarding the cause of the crystal separation.

5. The gabbros within the anorthosite are all of the same age and origin—segregations of basic ferromagnesian minerals within the differentiating magma—and are spheres or lenses and not plugs or knobs.

6. Transitional rocks between anorthosite and syenite originated through differentiation and not by assimilation.

7. Stringers with syenitic characteristics are consolidated "moth-

[1] Robert Balk, *Jour. Geol.*, Vol. XXXVIII (1930), pp. 289–302.

er-liquor" from which labradorite crystals originated and, hence, being squeezed between solidified aggregated masses of labradorite grains, are not dikes.

I believe I can recognize four distinct points of view which can be listed as follows: (1) that of Smyth, Cushing, Kemp, and me, (2) that offered by Bowen, (3) Miller's conception, and (4) that proposed by Balk.

There is, I believe, a very natural reason for these various interpretations: the field workers attacked the geology of the region in the early days before the establishment of the Geophysical Laboratory with its experimental attitude of mind and before the structural methods of H. Cloos[1] had been developed. Bowen made a reconnaissance of the Adirondacks and the Norian district of Canada to test his theory of differentiation by crystal settling. Then Balk made his thorough study of the structural lines of magmatic flowage of the intrusives. The point of view and methods of attack were decidedly different and we should not be surprised if the conclusions should differ.

AGE RELATIONS

In expressing the relative ages of the various Adirondack rocks, the geologists writing upon the subject give the average reader much difficulty. The terms "younger" and "older" as used by the majority of the field geologists, on the one hand, mean one thing, and to Balk[2] apparently something quite different. Balk is apparently so impressed with the concept that the Algoman anorthosite, nordmarkite-granite,[3] and gabbro are differentiation products of a parent

[1] H. Cloos, "Geologie der Schollen in schlesischen Tiefengesteinen," *Abh. d. Preuss. Geol. La. Anstalt*, N.F., Heft 81 (Berlin, 1920); "Der Mechanismus tiefvulkanischer Vorgänge," *Sammlung Vieweg*, Heft 57 (Braunschweig, 1921); *Der Gebirgsbau Schlesiens und die Stellung seiner Bodenschätze* (Berlin, Bornträger, 1922); *Einführung in die tektonische Behandlung magmatischer Erscheinungen (Granittektonik)*, Part I, *Das Riesengebirge in Schlesien* (Berlin, Bornträger, 1925).

[2] *Op. cit.*, p. 291.

[3] In 1925 I proposed to call the syenite-granite series laurvikite, nordmarkite, and quartz nordmarkite to bring out the similarity with the Norwegian rocks (*N.Y. State Mus. Bull. 261* [1925]; pp. 42–55). A. F. Buddington's paper on the "Adirondack Magmatic Stem" (*Jour. Geol.*, Vol. XXXIX [1931], p. 262), suggests that there are sufficient differences between the rocks of the Adirondacks and Norway to question the wisdom of the adoption of this nomenclature at the present time.

magma that to him Cushing's syenite dikes cutting anorthosite are not conclusive evidence that the syenite was "younger" (Balk's quotation marks). Balk argues that the syenite "dikelets" (Balk's term) may represent "mother-liquor" which was largely squeezed out from the crystallizing anorthosite and hence was not injected or intruded into the anorthosite. But it can be maintained that if the nordmarkitic rocks represent mother-liquor consolidation products, it never-

FIG. 2.—Nordmarkite "dike" transversing anorthosite 2 miles west of Gabriels in the St. Regis quadrangle.

theless crystallized later than that portion of the anorthosite in which "dikelets" occur.

Balk's view of the squeezing out of liquid magma, potentially nordmarkite, by the consolidating anorthosite is an attractive one if all the dikes of nordmarkite are "dikelets." I am using Balk's term. Is the nordmarkite "dike" (my quotation marks) transversing anorthosite 2 miles west of Gabriels in the St. Regis quadrangle,[1] as illustrated in Figure 2, a "dike" or a "dikelet"? It is 18 inches wide, N. 47° E. It is foliated. In 1917, I called this a "dike of syenite[2] cutting the anorthosite." Many others could be cited but the above

[1] H. L. Alling, "Geology of the Lake Clear Region," *N.Y. State Mus. Bull. 207–8* (1917), p. 117.

[2] Slides No. 607A and 1959.

is quite typical. Miller[1] reports other examples. Whichever view we take, I believe the statement that the nordmarkite (syenite) is younger than the anorthosite is nevertheless true.

I have had very little experience along the southern border of the anorthosite. It is in the Newcomb quadrangle[2] where Balk began his field work and it may be that he is applying his early acquired experience to the whole area. I would suggest that there may be a reason for the difference of views, distinct from the working theories. It may lie in the difference in our field areas. Along the northern and northwestern borders of the anorthosite core, nordmarkite "dikes" appear to cut the anorthosite. The northeastern margin is not available, due to the Paleozoic cover. In the south, according to Balk, there is a perfect gradation from one into the other. There may well be. I do not know. It may be I am too severe here, in attempting to explain some of the differences in opinion by a difference in field experience.

If the nordmarkitic eruptions were many separate masses as Cushing has so long maintained, or phacoliths as Buddington suggests,[3] they may well be of different ages: in the north and west may be localized later ones which cut the anorthosite, whereas in the south may be those closer in age to that of the anorthosite and grading into it. Is it necessary even according to Balk's interpretation to have all the syenite of the same age? Again we may conceive of various ages for the anorthosite. Balk has suggested that the southwestern portions of the anorthosite are the oldest and the northeastern portions the youngest. This does not appear to be in harmony with the above suggestion. The upshot of this discussion centers on the field facts, upon which the older field geologists and Balk appear to differ, and consequently their interpretations and generalizations are different.

Cushing's Long Lake geological map and his interpretation are illustrated by a tracing of the northeast corner of the quadrangle in

[1] W. J. Miller, "Geology of the Lake Placid Quadrangle," *N.Y. State Mus. Bull. 211–12* (1919), pp. 32–33; "Geology of the Schroon Lake Quadrangle," *N.Y. State Mus. Bull. 213* (1919), pp. 28–30.

[2] *N.Y. State Mus. Bull.* (awaiting publication).

[3] "Granite Phacoliths and Their Contact Zones in the Northwest Adirondacks," *N.Y. State Mus. Bull. 281* (1929), pp. 51–107.

Figure 3. The actual area is broken up by swamps and lakes so that much of the contact of the nordmarkite with the anorthosite has to be inferred. The map as I have drafted it brings out that (1) nordmarkite appears as dikes which seem to cut the anorthosite, and (2) the contact is not always between laurvikite (the basic syenite of

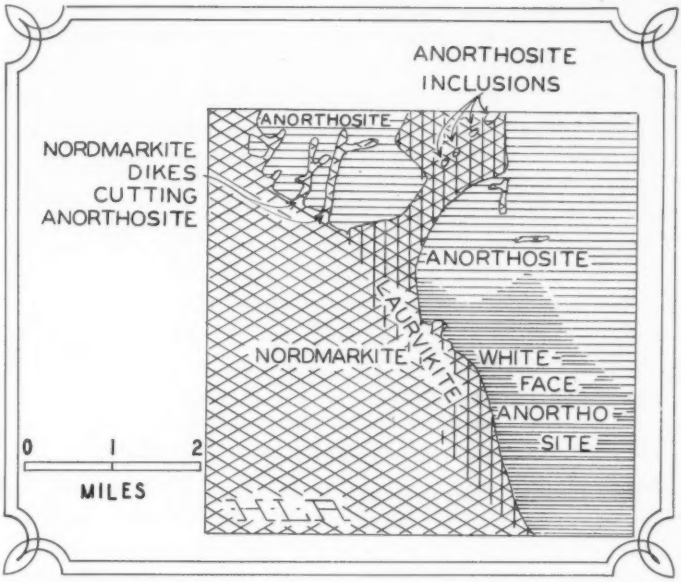

FIG. 3.—Sketch map of northwest corner of the Long Lake quadrangle, mapped by H. P. Cushing. In tracing it I have omitted the lakes and swamps in order to bring out the interrelations between the nordmarkite with its marginal phase, the laurvikite, the Marcy and Whiteface anorthosite. The interpretation here represented is that of the older Adirondack geologists, an interpretation not accepted by Balk.

Cushing) and Whiteface anorthosite (the anorthosite-gabbro) but that the nordmarkite cuts out the large portion of the Whiteface anorthosite. It can be suggested that formerly the marginal Whiteface swung toward the west in the area under discussion and that the nordmarkite has invaded it, swamped it, and produced an eruptive contact between the two. This interpretation is not favorable to an origin dependent upon differentiation *in situ*. Cushing[1] comments

[1] H. P. Cushing, *N.Y. State Mus. Bull. 115* (1907), p. 473.

as follows: "Between Follensby Pond and the Raquette is a considerable mass of syenite (nordmarkite) which cuts out nearly the whole of the gabbroic border (Whiteface anorthosite) locally, and holds great inclusions of it. . . . ." Again at an exposure to the west of the above, he says it "shows anorthosite cut by syenite, which is therefore younger, and granite cutting both the others and therefore youngest of all. . . . ." Balk, however, interprets the Whiteface, not as a chilled margin, but rather as that portion of the anorthosite which possesses foliation. He apparently distinguishes the rock by this means. The previous writers placed more dependence upon chemical and petrographical differences. Thus there exists, because of Balk's criterion, confusion regarding the proper distinguishing marks of the Whiteface. Balk,[1] therefore, says the Whiteface is *always foliated* (his italics), while others may just as conscientiously say the Whiteface is not always foliated. Cushing's Long Lake map, therefore, does not carry the same convictions to Balk as it did to the previous investigators. Figure 2 shows (1) that the nordmarkite comes in contact with massive anorthosite, or (2) that the nordmarkite cuts out a chill phase. This type of contact Balk says is rare.[2] The older geologists may reply that foliation is not a safe criterion to distinguish the Whiteface. Also the Whiteface rock may be interpreted as a chill phase without destroying the close consanguinity of the anorthosite and nordmarkite. Balk counters by saying that "the great majority of the syenite veins (the "dikes" of Cushing and others) occur in massive anorthosite and *avoid the foliated border phase*" (Balk's italics).[3] That is to say that the nordmarkite "dikes" in anorthosite "cut" the Marcy type and only occasionally "cut" the Whiteface phase of the anorthosite. If this is true then it is difficult to conceive of a method by means of which the nordmarkite, as a distinctly later (younger) rock, can cut only Marcy and miss the Whiteface type.

Balk has an effective argument here, provided the following points are granted: (1) that the Whiteface is only foliated anorthosite and not necessarily a chill phase, and (2) that the majority of the nord-

[1] *Jour. Geol.*, Vol. XXXVIII (1930), p. 291.

[2] *Ibid.*

[3] *Ibid.*

markite "dikes" "cut" Marcy anorthosite. The other geologists will not be inclined to accept these two statements, until additional field work has shown to what extent Balk's arguments are true.

ANORTHOSITE PEGMATITES

I have five microscopic slides of Adirondack anorthosite pegmatites as shown in Table II. Four were collected before Bowen's paper of 1917. My field notebook records a dozen more.

All of these are in the main body of the anorthosite of the Marcy type. In the field they distinctly cut the anorthosite with fairly sharp contacts, usually less than a foot in width, frequently very coarse in

TABLE II

ADIRONDACK ANORTHOSITE PEGMATITES

My Number	Quadrangle	Locality
34*a*	Mt. Marcy	Summit of Mt. Calvin
311	Ausable	Two miles east of Jay*
410	St. Regis	Just south of Mountain Pond*
1,459	Elizabethtown	Hurricane Trail
1,962	Lake Placid	South shoulder of Mt. Hamlin

* Illustrated in Figure 4.

grain, and exhibit the usual ramifications in directions so characteristic of pegmatitic dikes that I have no doubt that my interpretation is the correct one.

Under the microscope large grains of andesine-labradorite with antiperthitic borders make up the bulk of the rock. These borders occasionally show a slightly zonal character with a higher sodic feldspar content. The plagioclase in the immediate vicinity of the antiperthite rods exhibits a slightly different extinction angle from the bulk of the plagioclase and a slightly higher refractive index. Bowen[1] speaks of this as something unusual. Assured optical measurements of these antiperthitic blebs are very difficult because they are frequently thinner than the thin section itself and hence the optical properties of the "host" are added to that of the "guest" mineral. They appear to be a soda-rich feldspar akin to, or actually, anortho-

[1] *Op. cit.*, p. 221.

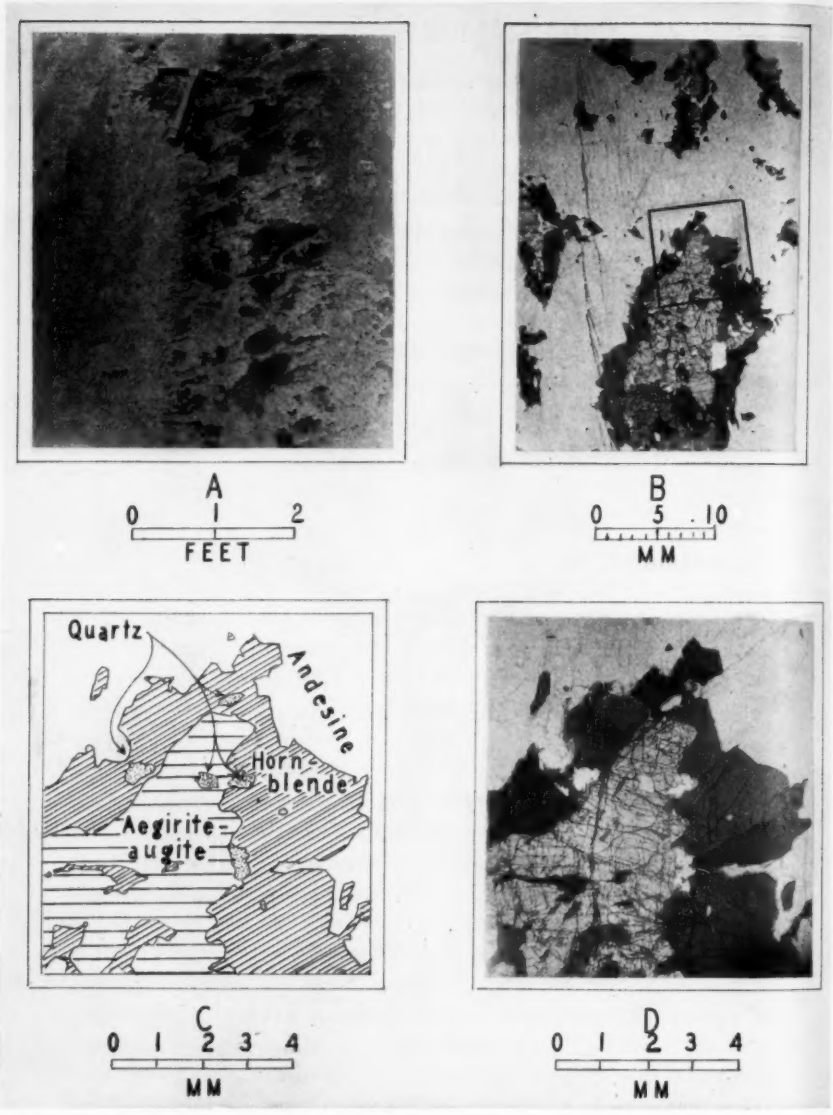

FIG. 4.—*A*, Field photograph of a 2-foot anorthosite pegmatite cutting anorthosite. Two miles east of Jay, Ausable quadrangle, 1916. *B*, Microscopic slide of anorthosite pegmatite cutting anorthosite. Just south of Mountain Pond, St. Regis quadrangle. Magnification originally ×3, ordinary light. The light groundmass is andesine, the light grey is aegirite-augite, with dark grey margins of paramorphic hornblende. The black mineral is magnetite. The area outlined is shown in *C*, slide No. 410. *C*, The area marked off in *B* enlarged originally ×11, showing paramorphic hornblende after aegirite-augite, slide No. 410. *D*, Photograph of *C*.

clase. The region immediately surrounding the blebs appears to have a lower potash content than the main crystal. Exsolution would well account for these microscopic facts. The theory of subsequent introduction of a soda feldspar and replacement would be in vogue. I feel that plausible arguments for exsolution and replacement are possible. Bowen,[1] Mawdsley,[2] and Barth,[3] on recasting chemical analyses of anorthosite, suggest that if the $KAlSi_3O_8$ is assigned to these blebs on the basis that they are orthoclase it leaves no excess to be assigned to the plagioclase. But as I have suggested elsewhere,[4] there may be a fallacy here since (1) the small size of the blebs, often thinner than the thin section, do not lend themselves to accurate graphic quantitative analysis. (2) The antiperthite grains are not orthoclase nor do they approach it in composition. I feel that my experience is opposed to a potash-free labradorite. Bowen seems to feel that replacement of the plagioclase feldspar by anorthoclase is suggested because the assignment of $KAlSi_3O_8$ to the blebs, resulting in potash-free plagioclase, militates against exsolution. I cannot believe that the argument is necessarily sound.

Some of the plagioclase in these pegmatites is oligoclase and andesine. Untwinned grains of plagioclase are surprisingly common but the refractive index is conclusive.

Interstitial grains of albite and oligoclase as well as anorthoclase distinct from antiperthitic blebs are late-stage crystallization phenomena. Quartz grains, sometimes in graphic intergrowth with plagioclase, frequently constituting as much as 15 per cent of the rock, show wavy extinction similar to quartz in granite pegmatites.

Hornblende, green and strongly paleochroic, with subordinate aegirite-augite and clearly paramorphic, constitutes the chief ferromagnesian mineral.

Magnetite, titanite, apatite, and zircon occur in smaller amounts. The secondary products are paragonite and scapolite which are derived from the plagioclase feldspars.

These pegmatites are therefore more acid than the main body of

[1] *Ibid.*

[2] J. B. Mawdsley, *Geol. Surv. Mem. 152* (1927).

[3] Tom. F. W. Barth, *Amer. Min.*, Vol. XV (1930), pp. 129–43.

[4] *Amer. Min.*, Vol. XV (1930), pp. 267–71.

the Adirondack anorthosite; they are not "pure" labradorite dikes. I do not see why they should be anything else but granodioritic in composition. I apply the term "anorthosite pegmatite" in order to bring out what I believe to be the true relationships.

The significant point here is that these pegmatites show that the anorthosite or the magma from which it crystallized possessed some mineralizers and gases. Daly says "a minimum amount." Buddington[1] states that: "differentiation [in the Adirondacks] is believed to have proceeded in much drier magmas than those of the more hornblendic Coast Range–Sierra Nevada series, and in slightly wetter magmas than the more completely pyroxenic Bergen-Jotun or Christiania [rocks]."

The lack of quantitative information here, as in the great majority of cases, prevents us from forming a clear conception of whether these illustrations are in agreement with Daly or whether the anorthosite possessed more volatile constituents than Bowen assigned to it. It certainly had some.

On the other hand, if these pegmatites are to be conceived as basic pegmatites from the potentially syenitic magma, as would in all probability be advocated by Balk, we find ourselves in the apparent difficulty of accounting for their basic characters. I believe that these pegmatites support the view that there may have been sufficient liquid associated with the labradorite crystals in the production of anorthosite to have produced these anorthositic pegmatites, a view which presents no serious difficulties to Balk.[2]

Bowen, offering a third alternative, has suggested that the parent magma was gabbroic, from which the Algoman intrusives differentiated. If we grant this postulate, we can, apparently, account for these pegmatites. I have discussed these at some length for I am convinced that they have been ignored by most writers on the rocks of the Adirondacks, and, furthermore, that they seem to be more in line with the views of the field geologists.

[1] "Adirondack Magmatic Stem," *43rd Annual Meeting, Geol. Soc. Amer., List of Abstracts* (1930), pp. 4–5. See *Jour. Geol.*, Vol. XXXIX (1931), pp. 240–63.

[2] Personally communicated July 29, 1931.

INCLUSIONS OF GRENVILLE IN THE ANORTHOSITE

Inclusions of older rocks in the anorthosite have been noted from many Adirondack quadrangles. Kemp[1] reported them ranging from a foot to hundreds of feet in size, on Baxter, Hopkins, Big Slide, Porter, Rooster's Comb, Gothics, and doubtless other peaks in the Mt. Marcy quadrangle, but did not express his ideas in regard to the degree of digestion they have experienced. Miller, Cushing, and others have repeatedly reported finding them.

My observations indicate, to me, that Grenville inclusions have suffered a good deal of corrosion and partial digestion. It may be that some of the streaked appearance of the border phases of the anorthosite is due to syntaxis and represents what I called "xenolithic phantom gneiss."[2] These observations can have several interpretations: (1) that these inclusions were corroded and partially digested by the anorthosite magma, if there was such a magma, or (2) that potentially syenite magma was the agent.

Grenville inclusions are common in the Whiteface anorthosite.[3] I have noted them in the Lake Placid and Ausable quadrangles. They show corroded margins and frequently show interpenetration of anorthosite stringers following the foliation planes of the Grenville sediments. This corrosive attack upon such inclusions or ghosts of inclusions has influenced Kemp[4] and me to say that "it is our suggestion that the Whiteface border phase is in part due to differentiation, and in part due to incorporation of foreign matters."[5] The latter explanation is offered particularly when the contact is with Grenville and the foliation is especially strong, for we were led to believe that in many instances the foliation of the intrusives was "due to super-imposition of either the bedding or foliation planes of the sediments upon"[6] the igneous rock, that is, that much of the

[1] J. F. Kemp, "Geology of the Mt. Marcy Quadrangle, Essex Co., N.Y.," *N.Y. State Mus. Bull. 229–30* (1920), pp. 33–38.

[2] Alling, "The Origin of the Foliation and the Naming of Syntectic Rocks," *Amer. Jour. Sci.*, Vol. VIII, No. 5 (1924), p. 24.

[3] See Miller, "Geology of the Lake Placid Quadrangle," *op. cit.*, p. 31.

[4] J. F. Kemp and H. L. Alling, *N.Y. State Mus. Bull. 261* (1925), p. 38.

[5] See Alling, *Amer. Jour. Sci.*, Vol. VIII, No. 5 (1924), p. 17. [6] *Ibid.*, p. 31.

foliation of the border phases of the anorthosite is inherited. I feel we ought to distinguish between superimposed foliation, on the one hand, and magmatic flowage governed by the presence of older rocks, on the other. There is to my mind a difference between foliation acquired by an intrusive because of magmatic replacement, *lit-par-lit* injection, and soaking, on the one hand, and pressure flowage due to magmatic currents directed by the invaded rock, on the other. The evidence of the inclusions and the nature of some of the foliation of the Whiteface anorthosite is open to a different concept of what happened than that given by Bowen or Balk.

Microscopic studies of the interpenetrated, soaked, and saturated Grenville sediments, which have been caught up as inclusions in the anorthosite, seem to point to an anorthositic liquid rather than to a syenitic melt. The introduced feldspars are dominantly plagioclase and only infrequently perthite. There is no difficulty in explaining the field facts provided we can grant an anorthositic magma. If the liquid that soaked the Grenville inclusions was the parent, potentially syenitic, magma from which labradorite aggregates crystallized and the residual melt squeezed out, it may be more difficult to account for what the microscope reveals. This raises the question whether a parent magma can differentiate within included blocks of country rock and leave plagioclase crystals behind, the liquid portions being squeezed out by the pressure of injection. The degree of magmatic corrosion of the inclusions of Grenville in the anorthosite can be ascertained through the application of the theory of foliation by superposition.[1] If the foliation of the anorthosite immediately surrounding such inclusions appears to flow around the inclusion, then we can conclude that either the amount of corrosion is small or that the protoclastic flowage of the anorthosite was dominant. But if the anorthosite surrounding such blocks presents foliation in conformity to that of the inclusion, then magmatic assimilation or reaction is a reasonable interpretation.

An example of anorthosite in granite was sketched by Kemp in 1898,[2] two miles north of west of Lewis, Ausable quadrangle. Subsequent study revealed the foliation of the surrounding anorthosite was patterned after that of the inclusion. In the St. Regis quad-

[1] *Ibid.*, p. 24.

[2] Kemp and Alling, *op. cit.*, Fig. 8, p. 55.

rangle,[1] a quarter of a mile south of Mountain Pond, inclusions of Grenville and anorthosite occur in nordmarkite and the nordmarkite apparently acquired a foliation from that of the inclusions (see Fig. 5).

As nearly as I can judge we must realize that the anorthosite or its parent magma (1) exhibits magmatic flowage, (2) was capable of acquiring a foliation by superimposition from included blocks of Grenville.

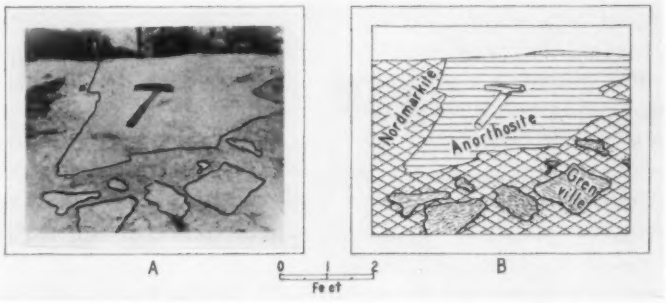

FIG. 5.—*A*. Field photograph of inclusions of Grenville and anorthosite in syenite. A quarter-mile south of Mountain Pond, St. Regis quadrangle, 1916. The boundaries of the inclusions have been outlined. *B*, Sketch of the same photograph with the inclusions labeled. Observe the foliation of the Grenville has been superimposed upon the adjacent nordmarkite.

Bowen[2] has suggested that the emersion of a plagioclase feldspar in a feldspathic melt does not suffer assimilation but rather reaction which involves no liberation of heat. The solution of a silicate in a magma requires absorption of heat, estimated by Bowen to be of the order of magnitude of the heat of melting.[3]

INCLUSIONS OF ANORTHOSITE IN ANORTHOSITE

Kemp[4] noted in the Elizabethtown sheet, near Split Rock Falls, inclusions of an anorthosite, exhibiting faint foliation, more py-

[1] Alling, *N.Y. State Mus. Bull. 207–8* (1919), Pl. 6, facing p. 122.

[2] *Op. cit.*, pp. 214–15; *Evolution of Igneous Rocks* (Princeton University Press, 1930), chap. x, pp. 174–223.

[3] *Evolution of Igneous Rocks*, p. 182.

[4] "The Geology of the Elizabethtown and Port Henry Quadrangles," *N.Y. State Mus. Bull. 138* (1910), pp. 37–39.

roxenic in composition, and showing corroded margins caught up in massive Marcy anorthosite. Kemp[1] says, "We have some evidence that . . . . inclusions of an older consolidated variety have been caught up in a later irruption." Balk describes this as "block structure." Kemp, naturally, sought an explanation of these anorthositic inclusions by postulating a later and separate intrusion. He noted, however, that biotite was far more abundant in the anorthosite of the southeastern portion of the Ausable quadrangle than in the Mt. Marcy sheet.[2] Hornblende is a constituent mineral in the biotite-rich varieties, probably indicating a greater content of water. This shows that there were geographical differences.

Both of these phenomena are in conformity with Balk's[3] suggestion that "the oldest part of the anorthosite lies in the southwest and the youngest portions are in the northeast." The inclusions described by Kemp are in the portion of the body midway between the younger and older extremes. Thus we have evidence that the anorthosite was a long time moving into position, later portions swamping fragments of earlier masses.

A study of the thin sections of the inclusions of anorthosite in anorthosite reveals slight differences in composition. These inclusions carry a slightly more basic plagioclase than the anorthosite host. This is very similar to Mawdsley's[4] observations in the St. Urbain area, Charlesvoix District, Quebec. Kemp noted an inclusion of anorthosite in anorthosite on Baxter Mountain in the Mt. Marcy quadrangle which exhibits chilled margins. Mawdsley argues that

> cutting of [the older, labradorite-bearing anorthosite] . . . . by another, seems to imply that the andesine anorthosite as a whole did exist in a liquid state and with the composition of andesine anorthosite . . . . there is no reason for supposing that the earlier formed, labradorite anorthosite did not also come into place in a liquid condition. . . . . Such a conception, of course, is irreconcilable with the general hypothesis put forward by Bowen,[5]

to which we may add Balk's views here as well.

[1] *N.Y. State Mus. Bull. 229–30* (1920), p. 33.

[2] *Ibid.*, p. 31.

[3] *Jour. Geol.*, Vol. XXXVIII (1930), p. 296.

[4] Mawdsley, *op. cit.*, p. 32.

[5] *Ibid.*, p. 33.

ANORTHOSITE-GRENVILLE TRANSITIONAL ROCKS

Kemp[1] in his description of the gneisses, in the Mt. Marcy quadrangle, associated with unquestioned Grenville sediments, expressed the view that some showed . . . . "close parallels in mineralogy with the . . . . syenites, or else so intimately involved with . . . . [them] that one may be sometimes in doubt as to where the metamorphosed ancient clastics end and the syenites begin."

I recall the puzzling times Professor Kemp and I had with such "rusty" gneisses in the Mt. Marcy, Lake Placid, and Ausable quadrangles. This field term is descriptive and nothing more. The summits of many of the mountains in the Marcy Range and lower peaks in the northern portion of the quadrangle showed affinities to the anorthosite in that these gneisses possessed labradorite augen and yet contained hornblende, biotite, and even quartz. These latter minerals suggested certain Grenville schists. Then we called these "anorthosite-Grenville rocks" without realizing at first that it was a generic as well as a descriptive term. Apparently the idea of magmatic assimilation accounts for these and the chief problem is one of nomenclature. Microscopic studies suggested that the liquids which soaked these Grenville sediments show affinities to both the anorthosite and the nordmarkite. Sometimes the kinship is closer to the anorthosite than to the nordmarkite and other occurrences, and vice versa. It is, of course, the cases where such soakings are assigned to anorthosite liquids that bear further study. It is from such rocks that the older geologists were led to ascribe sufficient fluidity or fluids to the anorthosite to produce hybrids.

The field geologists, therefore, regard the rocks as hybrids and maintain that the anorthosite possessed sufficient heat and gaseous materials to produce these syntectics. If the anorthosite did not, then the "rusty gneisses" are again a puzzle. Kemp[2] in the Mt. Marcy bulletin notes that such rocks can be "satisfactorily explained only as an old, surviving mass of Grenville gneiss, which became involved in the intrusive anorthosites and affected with more or less of the anorthosite substance." Such syntectics involve various kinds

[1] "Geology of the Mt. Marcy Quadrangle, Essex Co., N.Y.," *op. cit.*, p. 15.

[2] *Ibid.*, p. 36.

of Grenville sediments and chiefly the Marcy type of anorthosite. This seems to show that the Marcy anorthosite possessed sufficient "soaking" powers to produce these hybrid rocks. The anorthosite may not have stoped its way into position on any large scale, but it can be argued that its soaking and penetrating powers were considerable even though inferior to most granites. Hence, if these rocks were soaked by anorthositic substances, it may be difficult to account for them without an active anorthosite magma. Both Bowen and Balk are endeavoring to dispense with such a magma.

There is some difficulty with Balk's[1] statement that "whenever Grenville sediments are soaked or injected *lit-par-lit*, the intrusive component is syenite or granite, not gabbro or anorthosite. Grenville inclusions in the Mt. Marcy section of the anorthosite are not injected by the anorthosite." When I first read Balk's statement, quoted above, I was sure that it was incorrect and still believe it is if taken literally. What he probably means is that the mother-liquid from which labradorite grains crystallized was the liquid that saturated the blocks of Grenville sediments. Now this liquid, Balk proposes, was potentially nordmarkite and not anorthosite. Results of microscopic examination of these soaked rocks is not always in conformity with Balk's proposal. Labradorite crystals seem to have been injected into the ancient sediments as well as grains of perthite. To be perfectly fair to Balk, I can readily see that these labradorite grains may be regarded as anorthositic labradorite squeezed into the schists along with some mother-liquid which was potentially nordmarkite. I think it is necessary to interpret Balk's sentence rather broadly in order to avoid a clash of opinions with regard to the field and laboratory facts.

VARIATIONS WITHIN THE ANORTHOSITE

The anorthosite exhibits considerable variation in composition and textural relations. This is not surprising for a body of this size. Kemp noted the presence of biotite in the anorthosite in the Ausable quadrangle in contrast to the mica-free anorthosite of the Mt. Marcy area. The same thing may be said for hornblende. In the northeastern portions of the core, hornblende seems to take the place, in

[1] *Jour. Geol.*, Vol. XXXVIII (1930), pp. 300–301.

part at least, of the hypersthene. Other phases are very pyroxenic. The impressive accumulations of titaniferous magnetite at Lake Sanford[1] are in that portion which Balk believes to be older. Such deposits, due to differentiation, are not so extensively developed in the portions of the rock which Balk considers to be younger. Both of these observations show (1) that the anorthosite as such experienced differentiation *in situ*, or (2) that the younger portions were richer in volatile matters capable of forming biotite and hornblende, while the older was productive of titaniferous magnetite bodies, or (3) that the anorthosite is a tilted intrusive, one portion having suffered more erosion, revealing deeper magmatic conditions.

Foliation of the anorthosite has been appreciated by many of the geologists working in this area. They may, however, differ in regard to how much is due to magmatic flowage and how much is secondary, that is, gneissoid versus gneissic structure. I feel very confident that both terms are applicable. Balk, from his training under Cloos, would emphasize protoclastic foliation. It is there. But I feel equally confident that cataclastic features are also present.

BORDER PHASES OF THE ANORTHOSITE

The border phases of the Adirondack anorthosite have always played an important part in the discussions pertaining to this rock. It was Kemp who named one of the border types "The Whiteface Type."[2]

The Whiteface from the type locality and in the Elizabethtown–Port Henry areas is characteristically black and white in the hand specimen, usually finer grained than the Marcy type.[3] The ferromagnesian minerals are hornblende and augite: the plagioclase, andesine-labradorite, is usually chalky white, due in part to excessive alteration to secondary paragonite and scapolite. The granulation is largely protoclastic in nature. I have felt that some of this alteration of the plagioclase in the Whiteface type was due to the action of gases derived from associated magmatic sources.[4] The frequent

[1] Kemp, *U.S. Geol. Surv., 19th Rept.*, Part III, pp. 409–17.

[2] *N.Y. State Mus. Bull. 138*, pp. 35, 37.

[3] Miller, "The Adirondack Anorthosite," *Bull. Geol. Soc. Amer.*, Vol. XXIX (1918), p. 403.

[4] Kemp, *N.Y. State Mus. Bull. 229–30* (1920), p. 30.

gneissoid foliation of the Whiteface may account for the ease with which these gases penetrated, but it has been my experience that not all of the Whiteface type is foliated, in which case the plagioclase although white is not so thoroughly paragonitized. Naturally we have had different field opportunities and Balk has made more thorough studies of foliation in igneous rocks than I have. The point here is that it may not be safe to assume that this particular border phase known as the Whiteface type can be distinguished by its foliation. Furthermore, it is not necessarily true that all border rocks are Whiteface. Bowen discusses the border phases of the anorthosite without mentioning the name Whiteface.

RELATIONS OF THE NORDMARKITIC ROCKS TO THE ANORTHOSITE

Bowen and Balk state that there is a gradation between the anorthosite and the syenite, the latter being considered a differentiation product derived from the same magma *in situ*. Bowen recognizes that the syenite is slightly later in age and is not surprised to find that the syenite cuts the anorthosite. Balk, on the contrary, would have us believe that their ages overlap after they separated from the parent magma. Unfortunately, at the time Bowen wrote, the chief paper, with specific details about tongues of syenite cutting the anorthosite, was Cushing's Long Lake[1] bulletin. Since then the Lake Placid,[2] Schroon Lake,[3] Mt. Marcy,[4] Ausable,[5] and Lake Clear[6] bulletins have appeared, descriptive of areas dominated by the anorthosite. Very numerous field illustrations of such cuttings are now available.

Cushing, Kemp, and Miller emphasized the time-relations established by these observations. Bowen[7] and more recently Balk[8] seem to have seen the same facts but stress the close magmatic relationships between the nordmarkite and anorthosite. Balk actually ques-

[1] *Op. cit.*, pp. 480–84.

[2] Miller, *N.Y. State Mus. Bull. 211–12* (1919), pp. 32–33.

[3] *Bull. 213* (1919), p. 29.

[4] Kemp, *N.Y. State Mus. Bull. 229–30* (1921), pp. 28–38.

[5] Kemp and Alling, *op. cit.*

[6] Alling, *N.Y. State Mus. Bull. 207–8* (1917), p. 117.

[7] Bowen, *Jour. Geol.*, Vol. XXV (1917), pp. 209–43.

[8] Balk, *Jour. Geol.*, Vol. XXXVIII (1930), pp. 289–302.

tions the statement that the syenite intrudes the anorthosite. Most certainly there are bands, streaks, stringers, or masses of nordmarkitic syenite in the anorthosite. These give Cushing, Kemp, and Miller the impression that they are intrusive dikes or tongues. The commonly accepted view was, therefore, that the nordmarkite cuts the anorthosite.

Chill margins have not been noted in such dikes, and hence the suggestion was that the anorthosite was hot when the syenite entered. Balk prefers to consider these dikes solidified "mother-liquor," freezing in a mesh of plagioclase crystals of anorthosite while the latter experienced magmatic flowage. This flowage, Balk conceives, was responsible for the dikelike masses of nordmarkite and for the parallel foliation of the anorthositic walls as well.

Field observations led the older geologists to regard the nordmarkite younger than the anorthosite, and therefore the theory of differentiation to explain the transitional rocks between the anorthosite and the syenite was discarded. Bowen and Balk have revived this conception.

I have investigated many specimens both in the field and in thin sections. I had been impressed with the apparent assimilative and soaking powers of the anorthosite upon Grenville sediments in the Mt. Marcy quadrangle, so a similar explanation for the nordmarkite-anorthosite composite rocks was at once suggested for similar rocks in the Lake Placid and Ausable areas, and Kemp and I called them syntectics in the bulletin descriptive of the latter quadrangle. Bowen stated that he did not think that the intermediate types in the Lake Placid region were formed by the interaction of the two.[1] Balk likewise discards assimilation. Here we have two explanations. Cushing, Miller, and Kemp believed in an assimilative relation; Bowen and Balk advocate a magmatic differential gradation.

ANORTHOSITE-NORDMARKITE TRANSITIONAL ROCKS

Rocks situated between obvious anorthosite and nordmarkite which possessed characters of both have long been known. These are dark green nordmarkitic intrusives with labradorite augen, like blue eyes in a green gneiss; hence Kemp and I coined the term "sye.-

[1] Bowen, *Jour. Geol.*, Vol. XXV (1917), p. 517.

blue rock." In seeking an explanation of these gradational rocks, two possibilities were suggested: (1) they differentiated *in situ* from a common magma, or (2) they were assimilation products due to nordmarkite rocks invading and partially digesting anorthosite. The significant feature is that both the nordmarkite and the anorthosite show basic borders interpreted by the older geologists as the effect of chill.

It was formerly held that these rocks are just as likely to be syntectics or hybrids as transitional rocks due to differentiation. This lies in the fact that both the anorthosite and nordmarkite were thought to possess assimilative powers as is proved by the beautiful contact zone rocks,[1] Grenville-anorthosite and Grenville-nordmarkite hybrids, syntectics, mixed gneisses, complexes, etc. Kemp[2] says: "Explanations involving saturation with igneous matter, digestion and assimilation alone seems to make possible a reasonable conception of their complex development."

I have recently re-examined two anorthosite-nordmarkite boundaries with Balk's interpretation constantly in mind. One of these is in the Ausable quadrangle near Stickney Bridge, and the other in the Long Lake quadrangle near Tupper Lake.

THE STICKNEY BRIDGE LOCALITY

This locality is numbered "2" on map showing the Adirondack anorthosite, Figure 1. In 1919, a roadside quarry, half a mile east of Stickney Bridge in the northern part of the Ausable quadrangle, was visited. The rock is dark green and looked like the Algoman nordmarkite. On close examination some of the feldspar was seen to be striated and, more particularly, blue labradorite augen appeared every 3–6 inches on the face of the quarry. This was called "sye.-blue rock." In a petrographic study of a slide[3] the feldspars show considerable variation in composition and in texture. Much of the feldspar is plagioclase, a good deal is not twinned, and some grains

[1] Kemp, "Geology of the Mt. Marcy Quadrangle," *op. cit.*, pp. 17–27.

[2] *Ibid.*, p. 28.

[3] 1097. It was described in the Ausable Bulletin, *N.Y. State Mus. Bull. 261*(1925), p. 54. Figured in *Jour. Geol.*, Vol. XXXI (1923), Pl. II, facing p. 298 (erroneously called No. 1096), and was mentioned on page 354 of the same paper.

exhibit included blebs of a potash-rich feldspar in their margins. In 1923 this feldspar was called "oranite." The amount of potash feldspar is, however, small, and hence, the feldspar is more akin to the anorthosite. The ferromagnesian minerals likewise show variation. Hypersthene, aegirite-augite, diopside, and rich brown biotite occur. The aegirite-augite is believed to be responsible for the general green color of the rock and suggests the Algoman nordmarkite. Garnet, primary calcite (?), magnetite, rutile, zircon, apatite, and martite complete the list of minerals present.

Due to the glacial cover, the contact with the anorthosite was not available in 1919 but was judged to be near-by, as was so indicated upon the geological map of the Ausable quadrangle. In 1930 the locality was revisited. Close by the old quarry was a new opening which revealed the contact. With a distance of 15–20 feet a complete change from the Whiteface anorthosite to the "sye.-blue rock" occurs.

Additional slides[1] show that the feldspars show anorthositic types, labradorite, labradorite-antiperthite, and andesine. The nordmarkitic types include soda-orthoclasic-microperthite, and crypto-soda-microcline. Likewise the pyroxene can be classified: the anorthositic type is hypersthenic augite and the nordmarkite variety is aegirite-augite.

The magnetite of the transition rock is clearly of several stages. Small octahedral grains are the product of early crystallization but most of them are later. It is seen replacing the anorthosite type of augite and the plagioclase as well as the biotite. Consequently, I believe the biotite belongs to the anorthosite. Minerals distinctly of nordmarkitic affinities do not seem to be replaced as readily. This locality is near Palmer and Arnold Hills, where abandoned magnetite mines occur. I believe the source of these ore bodies is the nordmarkite (syenite) and not the anorthosite and hence I can suggest that the magnetite, found replacing anorthositic minerals in the "sye.-blue rock" near Stickney Bridge, came also from the nordmarkitic group of rocks.

The Whiteface anorthosite, exhibited in the new quarry, is composed of labradorite, a few grains of which are untwinned, pale

[1] 4527, 4527a.

diopside augite, paleochroic aegiritic augite, hornblende, quartz, magnetite, titanite, and zircon. There is a possibility that the slides studied contain a little potash-rich feldspar, but its identification is difficult due to the smallness of grain. Alteration of the plagioclase to secondary products, chiefly paragonite, cloud the labradorite in a characteristic manner. The aegirite-augite certainly suggests nordmarkitic affinities. Consequently, the border phase of the anorthosite, as seen in the new quarry, exhibits characters of both rocks and is transitional. Quantitative measurements with the Wentworth micrometer[1] result in Table III.

TABLE III

PERCENTAGE OF ANORTHOSITIC AND NORDMARKITIC MINERALS IN QUARRIES NEAR STICKNEY BRIDGE

	"Sye.-blue Rock" (Per Cent)	Whiteface Anorthosite (Per Cent)
Anorthositic Minerals. . .	16	72
Nordmarkitic Minerals. .	84	28

THE LONG LAKE LOCALITY

The second locality, numbered "1" on Figure 1, shows both anorthosite and nordmarkite in a quarry for road stone beside the main highway from Saranac through Tupper Lake to Cranberry Lake, midway between the southern end of Upper Saranac Lake and the town of Tupper Lake. The contact is sharp and well defined. The actual line of contact is marked by slickensides but not by a zone of crushing. The amount of movement is not determinable; it may be considerable or only a few inches. My feeling about the matter is that the throw is not great.

A slide cut from a specimen of the nordmarkite taken 3 feet from the contact shows characteristic nordmarkite differing but slightly from the rock miles away from the anorthosite. Perthite, quartz, plagioclase, hypersthene, and aegirite-augite make up the bulk of the rock with accessory magnetite, hornblende, garnet, apatite, and zircon.

[1] C. K. Wentworth, *Jour. Geol.*, Vol. XXXI (1923), pp. 228–32; W. F. Hunt, *Amer. Min.*, Vol. IX (1924), pp. 190–93; H. L. Alling and W. G. Valentine, *Amer. Jour. Sci.*, Vol. XIV, No. 5 (1927), pp. 50–65.

The anorthosite shows Marcy characteristics, labradorite abundantly altered to secondary products. There is augite, garnet, magnetite, and a little quartz present. The quartz seems to be a normal constituent of the rock, but the garnet appears to be of later age. The alteration prevents seeing whether or not the plagioclase possesses antiperthitic margins. Here the gradational character of the contact is much more abrupt, possibly explained in part by the presence of the fault. The weathering of the anorthosite is clearly supergene, due to surface waters following the fault cracks. It is not hydrothermal as is often the case with the Whiteface type.

Petrographic study of these exposures is given because the field and laboratory study was done in 1930 with the views of recent writers in mind. It reveals, to my mind, confirmatory evidence that, when the two rocks occur in contact, a zone of intermediate rock often occurs. Cushing recognized that both the syenite and the anorthosite show these basic marginal phases; there seems no disagreement upon these facts. He also noted, as I have, that nordmarkite comes into contact with the Marcy anorthosite as it does here without these basic margins even in the absence of faulting.

INTERPRETATION

POSITION OF TRANSITION ROCKS

Bowen and Balk offer in explanation of the above the view that the nordmarkite is a differential product from the same magma that gave rise to the anorthosite. They go farther than that: they suggest that there was little or no difference in time between the injection of the anorthosite and nordmarkite; that we now, through erosion, can examine the place where this differentiation took place. Balk particularly seems to stress this view. Such transitional rocks, of course, occupy a midway position, both physically and areally, between pure anorthosite and pure nordmarkite. Figuratively, one rock overlaps the other. The width of this overlapping varies from several miles to a fraction of a mile. In the case of the Stickney Bridge occurrence the zone is about a mile wide. Within this zone laurvikite, "sye.-blue rock" (Keene gneiss), and the Whiteface anorthosite are to be included. The most general interpretation placed upon the laurvikite and the Whiteface is that they are basic

border phases of the nordmarkite and anorthosite, respectively, due to effects of chill. This means that both the anorthosite and nordmarkite are nearly but not necessarily contemporaneous. It is upon the "sye.-blue rock" that this discussion centers.

TRANSITION ROCKS SHOW REPLACEMENT

Petrographic study reveals that the minerals of the transition rocks can be classified under the heads in Table IV.

TABLE IV

A	B	C	D	E
Anorthositic Minerals	Nordmarkitic Minerals	Introduced Minerals	Paramorphic Minerals	Metamorphic Minerals
Labradorite-andesine	Microperthite			Garnet
Hypersthenic-augite	Aegiritic-augite		Hornblende	
Biotite				
Quartz	Quartz			
Magnetite	Magnetite	Magnetite		
Apatite	Apatite			
Zircon				
		Pyrite		
Titanite				

The order of crystallization of the minerals of the anorthosite appears to be: (1) zircon and apatite, (2) magnetite, (3) biotite, (4) hypersthenic augite, (5) labradorite, (6) quartz.

The crystallization of the nordmarkite is similar: (1) zircon and apatite, (2) magnetite, (3) aegirite-augite, (4) microperthite, (5) quartz.

Distinction of all of the above minerals in the transition rocks is of course impossible in every instance. This is especially true of those minerals sparingly occurring in small grains. But the essential minerals can be, I believe, accurately assigned to the above-mentioned classes.

Transition rocks under the microscope furnish me evidence that

at least in part the nordmarkitic minerals have replaced the anorthositic minerals (Table V).

It is the introduced magnetite that furnishes a direct evidence of replacement. Its selection of anorthositic minerals is quite clear even though the cause of this behavior is not fully understood. I believe this magnetite is non-titaniferous and is akin to the nordmarkite.[1] This magnetite is found replacing labradorite-andesine, biotite, hypersthenic augite, and quartz. Except for quartz, which is common to both the anorthosite and the nordmarkite, the replaced minerals

TABLE V

Anorthositic Minerals	Replaced by	Nordmarkitic Minerals
Labradorite-andesine.....	Replaced by	Microperthite
Hypersthenic-augite.....	Replaced by	Aegiritic-augite

are those of the anorthosite. Figure 6, *C* and *D*, present microscopic evidence for this.

This phenomenon of replacement I present to the reader as a new contribution to Adirondack geology.

The magnetite in replacing the anorthositic minerals is obviously late in the order of crystallization, some would call it "deuteric" in spite of the present uncertainty regarding the exact meaning of the term. To some the use of the word renders the phenomenon less significant in attempting to cast light upon the relations between the rocks.

The replacement of the anorthositic minerals by minerals of the syenite can be interpreted to mean that after the aggregation of labradorite grains, the remaining liquid, potentially syenite, replaced them. This can be regarded as favoring Balk's contentions.

This replacement of anorthositic minerals by syenitic fluids does not necessarily mean assimilation. Reaction would be a better term. The replacement relations between the anorthosite and the syenite do not, it seems to me, necessarily support any one theory. The older conception of the syenite as younger than the anorthosite implies that the syenite would come in contact with the solidation product of the same magma from which the nordmarkite came. And yet the

[1] Alling, "The Genesis of the Adirondack Magnetites," *Econ. Geol.*, *Vol.* XX (1925), pp. 335–63.

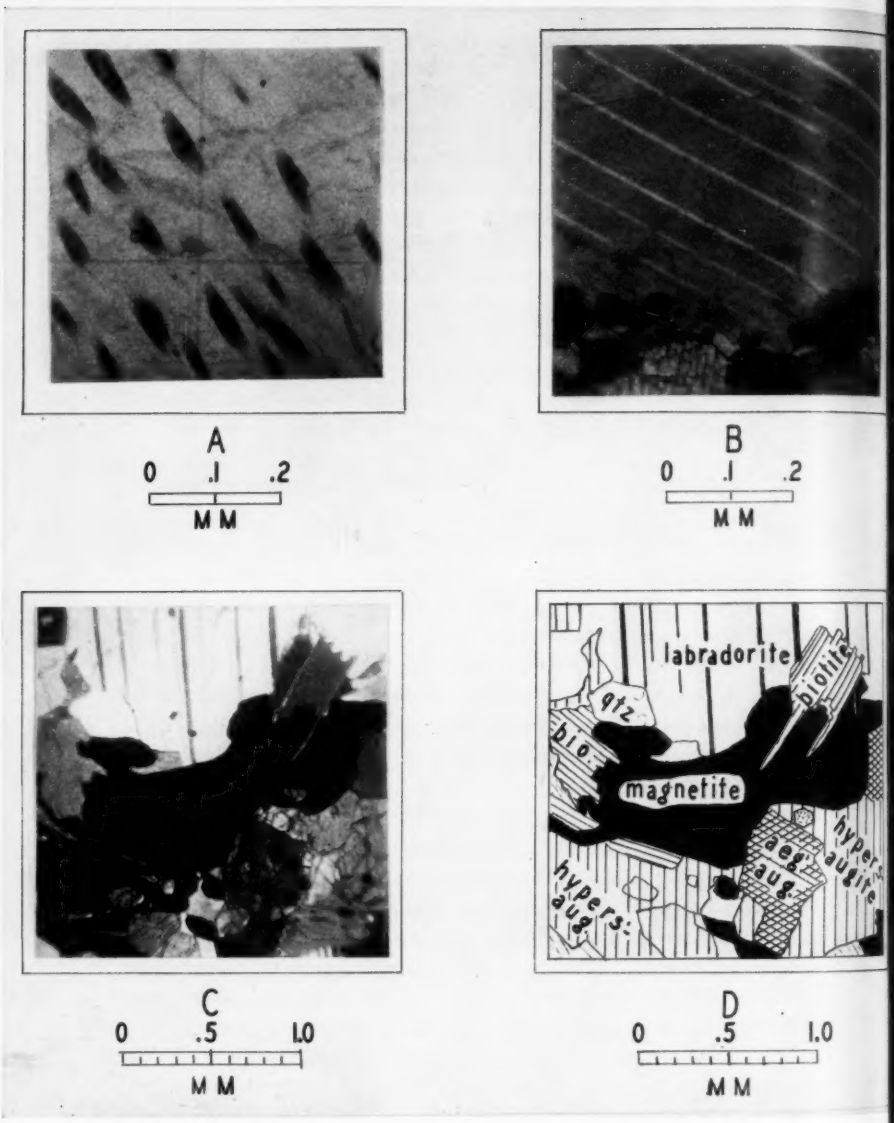

FIG. 6.—*A*, Photomicrograph of anorthoclasic blebs in margin of labradorite grain, northeast corner of La Lake quadrangle. See locality No. 1 in Figure 1. Polarized light. Magnification originally ×148, slide 45 *B*, Anorthoclasic blebs in margin of labradorite in basic anorthosite. $3\frac{3}{4}$ miles west of the town of Saranac La Polarized light. Original magnification ×143, slide 393. *C*, Magnetite replacing anorthositic biotite, labrador and aegirite-augite. Stickney Bridge locality, Ausable quadrangle, locality No. 2 on Figure 1. Polarized lig Original magnification ×40, slide 4527. *D*, Labeled drawing of the same view as is photographed in *C*.

older Adirondack geologists claim assimilation. The four theories under discussion approach the problem of the relations between the anorthosite and the nordmarkite really from much the same premise: products of a common magma. The older investigations were rather noncommittal regarding the parent magma. Bowen suggests that it was a gabbroic one, a view later adopted by Miller.[1] Balk refers to the parent magma as of more siliceous composition than a gabbro. This is consistent with the majority of the field facts and may explain all of them. It was, it would seem, the finding of the so-called dikes of nordmarkite apparently cutting the anorthosite that compelled the older geologists to separate the two rocks by an interval of time. This placed the emphasis upon assimilation. Bowen and Balk reduced the time-difference to nearly zero and hence differentiation can be considered. I ask in all seriousness why assimilation is thereby ruled out. Because differentiation would exhibit the close kinship of the two rocks? This is a fundamental concept of both Bowen and Balk. They must assume this to dispense with an anorthosite magma in order to explain this labradorite rock without postulating magmatic temperatures in excess of those known or believed to exist. As a matter of fact, the geologists whose work preceded them have all along maintained close kinship between the two rocks. The time-interval was not great. They argued that the nondiscovery of chill margins on the so-called dikes of syenite in the anorthosite was due to the hot condition of the anorthosite, and hence these dikes were injected into the anorthosite soon after the solidation of labradorite grains. Balk states that these stringers of syenite are in reality residual "mother-liquor" freezing between aggregates of labradorite. It may be that many are. I am not prepared to say that all of them are; however, the fact remains that all geologists agree that there is a close kinship between the anorthosite and the nordmarkite. There is really a great deal in common in all the theories.

THE LAURENTIAN GRANITE

Cushing,[2] in the Thousand Island region, divided the granitic intrusives into the Laurentian or older group, and the Picton (Algo-

[1] *Bull. Geol. Soc. Amer.*, Vol. XXIX (1918), p. 461.

[2] *N.Y. State Mus. Bull. 145* (1910).

man) or younger group. Smyth,[1] in the early days, recognized and described two granites and tentatively suggested that they were of contrasted ages. Likewise Baker[2] in the Kingston, Ontario, area recognized two granites. J. F. Wright[3] in the Brockville-Mallorytown area, which is just across the St. Lawrence from the Thousand Island region, noted "no evidence of granites of two ages. . . . . The granite found was equivalent to Cushing's Laurentian." He further says, ". . . . Cushing has [no] positive evidence of two periods of granitic intrusion in this region. . . . . In fact, Cushing . . . . says 'such a younger age for this granite then seems to us in the highest degree probable, though it falls somewhat short of actual demonstration.' "[4] Wright is more inclined to accept Miller's view[5] that positive evidence of two granites is inadequate and consequently he and Miller do not accept Cushing's Laurentian granite, and Wright does not accept the younger (Algoman) granite, on the evidence so far available.

It should be noted that Miller recognized only those granites in the Adirondacks which Cushing called Picton (Algoman) while Wright found positive evidence only for those granites which Cushing assigned to the Laurentian.

In recent years Smyth and Buddington[6] have re-examined the granites of the northwest Adirondacks and are less committal regarding their age. They recognize various types such as the Alexandria, Herman, and the Picton, but are unable to substantiate Cushing's original claims. In fact, in some localities they offer evidence that the so-called Laurentian is younger than the syenite. Buddington[7] believes that two and only two types of granites are established in the northwest Adirondacks but that they belong to a single magmatic invasion. It is possible that some of the Alexandria type is slightly younger than the coarse and porphyritic Herman granites. Balk[8] tells me that he has reached the conclusion, from his work in

[1] C. H. Smyth, *N. Y. State Mus. Rept. for 1899*, p. R92.

[2] M. B. Baker, *Ont. Bur. Mines Ann. Rept. 25*, Part III (1916), pp. 1–36.

[3] J. F. Wright, *Ont. Bur. Mines Ann. Rept.* (1926).

[4] *N.Y. State Mus. Bull. 145*, p. 42.

[5] *Bull. Geol. Soc. Amer.*, Vol. XXV (1914), pp. 243–63.

[6] New York State Museum Bulletins (in press).

[7] Personally communicated January 22, 1931.

[8] Personally communicated July 29, 1931.

the Newcomb quadrangle,[1] that the amount of Laurentian granite in the Adirondacks is very small. But it may be that the Newcomb quadrangle is not the ideal area to study the amount of Laurentian granite in the Adirondacks.

If both Bowen and Balk desire to omit all but a passing reference to the problem of the ages of the Adirondack granites, they may do so for at least two reasons: (1) that due to the obvious confusion expressed or implied in the writings of previous geologists, they desire to be noncommittal, or (2) that they question the validity of the claim that the Laurentian should be a part of the scheme of things.

In obtaining a large view of the geology of the Adirondacks, reliance must by necessity be placed upon the old map of F. G. H. Merrill. The undivided gneisses were listed as "Adirondack gneiss." Of course, there is no such rock. A good deal of this "gneiss" belongs to the Algoman nordmarkitic series, the syenite-granite of Miller. But Cushing maintained that it may contain rocks that are Laurentian in age. In using available geological maps for a composite map of the entire Adirondack region and calling, through necessity, the Adirondack gneiss "Algoman," we find that Cushing's Laurentian granite shows up in the northwestern portion of the Adirondacks. In the southeastern area, the same rock appears. The same is true of small areas on the Ausable sheet. But the territory between these occurrences on the map does not show any. Miller did not map the Laurentian granite. Is the Laurentian series of gabbros, or what were once gabbros, monzonites, diorites, and granites, missing in the quadrangles mapped by Miller? It may be that it occurs. Granite believed to be Laurentian was found in the Lake Placid quadrangle, southeast corner, near Franklin Falls. Miller[2] shows an excellent photograph of the inclusion of this granite in Whiteface anorthosite. He, however, calls it an inclusion of "Grenville gray gneissoid feldspar-quartz-garnet gneiss."[3]

Rocks which I believed to be of the Laurentian type have been found in the Bolton, Whitehall, and Luzerne sheets and doubtless

[1] "The Geology of the Newcomb Quadrangle" (now awaiting publication as a *N.Y. State Mus. Bull.*).

[2] *N.Y. State Mus. Bull. 211–12* (1919), Pl. XI.

[3] I wonder what is meant by a "gneissoid gneiss" of sedimentary origin. "Gneissoid" to me means magmatic flowage during crystallization of an igneous rock.

will be found in many others.[1] Several exposures were found in the Ausable quadrangle[2] of sufficient size to justify mapping. It may be that in the areas to the west of the involved eastern portions, larger masses may be found. Cushing's picture of the Adirondack region "is that a complex of Grenville, resting on orthogneiss, existed in the region at the time of the intrusion of the anorthosite-syenite group; that much of this still remains in the region and that the later intrusives broke through this complex in separate masses, instead of forming one great body."[3]

Here my point is that what Miller has mapped, and he has mapped the majority of the Adirondack quadrangles, as syenite-granite may not be exclusively Algoman syenite-granite but that there may be masses of Laurentian granite as well, and hence any theory involving a direct genetic relationship between the nordmarkitic series and the anorthosite should recognize that the granitic rocks may not be all of the same age and a continuous ring surrounding the anorthosite core.

Bowen and Balk give me the impression that they believe that the Laurentian is not important in a discussion dealing with the petrogenesis of the anorthosite. To this I agree. But in offering theories to explain the relation between the anorthosite and the granitic rocks of the Adirondacks, the Laurentian granite may be an important matter. The acceptance of Miller's position that there is insufficient evidence for the recognition of the rock unit renders the proposals of Bowen and Balk less convincing to some of the older geologists.

POSSIBLE ANTICLINAL STRUCTURE OF THE ADIRONDACKS

I recognize the possible anticlinal structure of the whole Adirondacks. The relief map of New York state in the museum at the University of Rochester shows a decided trend in the elongation of ridges and valleys, as was so strikingly shown by Ruedemann's[4]

[1] Alling, *Amer. Jour. Sci.*, Vol. XLVIII, No. 4 (1919), pp. 47–68.

[2] Kemp and Alling, *op. cit.*, pp. 31–33.

[3] Cushing, *Jour. Geol.*, Vol. XXV (1917), p. 507; *Amer. Jour. Sci.*, Vol. XXXIX, No. 4 (1915), pp. 288–94.

[4] Rudolf Ruedemann, *Amer. Jour. Sci.*, Vol. VI (1923), pp. 1–10; *Nat. Acad. Sci. Proc.*, Vol. V (1919), pp. 1–6; *Pan. Amer. Geol.*, Vol. XXXVIII (1922), pp. 367–77; *N.Y. State Mus. Bull. 239–40* (1922), pp. 65–152; *ibid.*, *260* (1925), pp. 71–80.

very suggestive papers. This is revealed by the topography (here in relief)[1] and alinement of the color patterns of rock units. The geology of the model was secured from those maps which I feel indicate the field relations as I believe they exist. Some would say that I am prejudiced in favor of areas I have seen and mapped. I am. The "grain"[2] is from southwest to the northeast. I am going to assume this to be true.

From the Rochester relief map I can see a regular pattern of the Grenville sediments. There is a similar arrangement of the Laurentian granite *when it has been recognized and mapped*. These rocks are situated in the northwestern Adirondacks and in the southeastern districts and largely absent in central portions. This suggests a great structural northeast-southwest trending anticline or anticlinorium; under this conception the patches of Grenville are truncated limbs. The Laurentian granite is situated with, involved in, and geographically associated with the Grenville.

Now if this conception is at all valid, then the center of the anticline is to a large degree nordmarkitic in nature, together with the anorthosite and associated Algoman gabbros. The Grenville series and the Laurentian granite are to a large degree absent.

THE KEENE AND PLACID INLIERS

In seeking for confirmatory evidence that the parent magma differentiated into an overlying sheet of syenite-granite, a middle layer of anorthosite, and a bottom zone of gabbro and peridotite, Bowen regarded the masses of "Adirondack gneiss," shown on the old state map of Merrill in the Placid and Keene areas, as inliers within the anorthosite and hence remnants of such an upper layer of syenite. Cushing, in 1917, in replying to Bowen's paper agreed with him that "if . . . . the anorthosite body, while cooling, developed a syenite cover, since removed by erosion, ... that the Placid and Keene inliers of syenite may be remnants of this cover. If so, it would be in their vicinity that true transitional rocks between syenite and anorthosite would be most likely to occur."[3]

[1] Horizontal scale 2 miles to the inch. Vertical exaggeration 2½ to 1. The entire map constructed from the latest topographic U.S. Geological Survey maps.

[2] Buddington, *N.Y. State Mus. Bull. 281* (1929), pp. 51–107.

[3] Cushing, *Jour. Geol.*, Vol. XXV (1917), p. 506.

At this time active field-mapping was in progress in the Lake Placid and Ausable quadrangles by Miller and Kemp, I assisting the latter. The results of this mapping showed that the Placid inlier was a misnomer[1] in that it proved to be a re-entrant of syenite connected with masses in the Saranac quadrangle. There is, however, evidence for the Keene inlier, and for an additional one which I shall call the Keene Valley inlier. The rocks of the Keene inlier have been studied by the three of us, Kemp, Miller, and myself. What do we find? Some nordmarkite (syenite), but the inlier is by no means entirely of that rock. There are outcrops of Grenville sediments, Keewatin (?) greenstone inclusions, Algoman gabbros, and all sorts of mixed types: Grenville-nordmarkite syntectics, Grenville underlain by anorthosite, and anorthosite-nordmarkite transitional rocks, namely, Miller's Keene gneiss.

THE KEENE VALLEY INLIER

Figure 1 shows in the northeastern corner of the Mt. Marcy quadrangle an additional inlier which was not generally appreciated in 1918, as is shown by Miller's[2] comment: "Whether the Keene syenite area actually connects with this broad tongue is not known because of lack of detailed field work. In any case, if there is no direct surface connection, the space between must be narrow." The Mt. Marcy map shows the two areas to be distinct. There is a Keene inlier and a Keene Valley inlier. I have examined thin sections of the rocks from the Keene Valley inlier and conclude that many of the exposures reveal "sye.-blue rock," some of which is mixed with Grenville. The rocks present a transition between nordmarkite and anorthosite.

Cushing remarks that the anorthosite shows differentiation toward anorthosite-gabbro and *not into syenite* (my italics). Such transitional rocks between anorthosite and syenite are due to "assimilative attack of a later intrusion [nordmarkite] upon an earlier [anorthosite] and is not differentiation *in situ*."[3]

The evidence secured in these inliers does not strengthen the be-

[1] Miller, *Bull. Geol. Soc. Amer.*, Vol. XXIX (1918), p. 435.

[2] *Ibid.*, pp. 435–36.

[3] Cushing, *Jour. Geol.*, Vol. XXV (1917), p. 505.

lief in Bowen's postulated nordmarkitic cover. The older geologists seem to regard them as separate intrusives which have invaded the anorthosite from below. These views are in contrast to those offered by Balk.

THE GABBROS

The basic rocks in the Adirondacks present problems peculiar to themselves. No two geologists use the word "gabbro" with the same connotation.

Kemp was the first to recognize them along Lake Champlain.[1] He called them "basic" gabbros. He felt that inasmuch as the anorthosite is a plagioclase-rich gabbro, as it is, that these darker, smaller masses should have a distinctive adjective to describe them. He satisfied himself that they cut the nordmarkitic rocks and hence were later.

In the northwestern Adirondacks dark stringers of amphibolitic rocks were found. Martin[2] particularly studied these and called them gabbrodiorites, metagabbros, etc. Some he suggested to be metamorphosed limestones, to others he assigned an igneous origin. Cushing felt[3] that some represented the oldest intrusive in the mountains. The concept of gabbros of several ages was developed. Miller experienced a reversal of opinion.[4] He first believed them to be post-syenite–granite in age. Then for a short transitional period he held to two ages and later he recognized only the older group of gabbros.

Meanwhile I had found evidence, particularly in the southeast central Adirondacks, of gabbros of still other ages. Hence, the term "gabbro" today carries no age meaning. Into this discussion Gillson and his associates[5] came and appeared to be confused. However, this confusion is more apparent than real. There are gabbros of several ages.[6] Now it is obvious that it is only the Algoman gabbros

[1] *Bull. Geol. Soc. Amer.*, Vol. V (1894), pp. 218–21.

[2] J. C. Martin, *N.Y. State Mus. Bull. 185* (1916), p. 57.

[3] *N.Y. State Mus. Bull. 115* (1907), p. 466; personal correspondence, November, 1917.

[4] Miller, *N.Y. State Mus. Bull. 213–14* (1919); N.Y. State Museum bulletins since 1919.

[5] J. H. Gillson, William H. Callahan, and William B. Millar, *Jour. Geol.*, Vol. XXXVI (1928), pp. 149–63.

[6] Alling, "The Ages of the Adirondack Gabbros," *Amer. Jour. Sci.*, Vol. XVIII, No. 5 (1929), pp. 472–76.

that directly concern us here, provided each occurrence is properly determined to be that age (Table VI).

Balk[1] says that he found that gabbro and syenite *grade* (my italics) into each other except where locally sheared so that "massive gabbro lies directly against nearly (but not ever quite) massive" country rock. "Such exposures have probably *suggested* [again my italics] a younger age of the gabbros." He refers to the paper by Gillson, etc.,

TABLE VI

GABBROIC ROCKS IN THE ADIRONDACKS

Age	Reference
5. Algoman ("Basic") gabbros	Kemp, *Bull. Geol. Soc. Amer.*, Vol. V (1894), pp. 218–21
4. Post-Laurentian–pre-Algoman	Alling, *N.Y. State Mus. Bull. 199* (1918); *Amer. Jour. Sci.*, Vol. XLVIII (1919), p. 60
3. "Laurentian" metadiorites (?)	Cushing, Martin, Buddington, and others
2. (Grenville, metamorphosed lms.) Paramphibolite	Many references
1. Keewatin[?] greenstone	Kemp and Alling, *N.Y. State Mus. Bull. 261* (1925), pp. 11–16

in which gabbros younger than the syenite are described. Balk says "if such gabbros actually exist, they are of no immediate importance in the present problems."[2]

It is essential that we remember that there may be gabbros of several ages in the Adirondacks because an intrusive which "cross-cuts the foliation of any other rock . . . . is ordinarily considered of definitely later age" and therefore does not possess "close consanguineous relations" with the rock it cuts.[3] Balk does not seem to have found gabbro cutting anorthosite.

However, Balk's field experience has been different from mine or else he has interpreted what he sees in a different manner. In any case, he gives an entirely different picture from what most previous field geologists have gathered from the field. He says "the typical appearance of a gabbro (knob) is a round body, resting on a saucer

[1] *Jour. Geol.*, Vol. XXXVIII (1930), p. 293.

[2] *Ibid.*

[3] Personal communication, July 29, 1931.

shaped floor of strongly foliated anorthosite (or syenite), about like an egg in a nest."[1] I have seen some of the gabbros he mentions as particularly exhibiting this feature. I am not at all certain that the floor can, with such confidence, be ascertained. I fear that much has been inferred, strongly influenced by his thesis: that the anorthosite, nordmarkitic rocks and associated noritic gabbros are "closely related, consanguineous members of common 'parent magma.' "[2] Now it may be that I have failed to find the evidences that led Balk to his conclusion. Miss Fowler[3] reports that the gabbro lenses within the anorthosite in the Laramie Mountains "show a close relationship to the anorthosite, ... where it grades into the anorthosite." Furthermore, it is quite possible that such gradations, which I have not seen, were the cause of Miller's change of opinion. If Miss Fowler and Balk are right then both Miller and the older geologists are wrong, Miller because he claims the gabbros are older, and Kemp and others younger, than nordmarkite.

It may be questioned whether erosion has been deep enough to expose the floors of these gabbro lenses. It may be that some of the Algoman gabbros, although closely related in age to the anorthosite, came in later as separate masses.

THE CONFLICTING THEORIES

Geologic studies of the Adirondack anorthosite have produced four major theories of origin. Of course there are minor ones which modify each to some extent but in this broad survey it is necessary to condense them. For ready reference I have attempted to contrast these by parallel columns. In doing so I may, of course, misinterpret some of the views held. I have labored under the handicap of not being entirely neutral in this controversy (Table VII).

CONCLUSIONS

The tabulation in Table VII would seem to show that the four contrasted theories are irreconcilable in some respects and not in others. Bowen's paper called our attention to the possible laccolithic

[1] *Jour. Geol.*, Vol. XXXVIII (1930), pp. 294–95.

[2] *Ibid.*, p. 290.

[3] Katharine S. Fowler, "The Anorthosite Core of the Laramie Mountains, Wyoming," *Amer. Jour. Sci.*, Vol. XIX, No. 5 (1930), pp. 373–403.

TABLE VII

Majority of Adirondack Geologists	Bowen 1917	Miller 1918	Balk 1930
I Anorthosite Injected as a Magma	II Anorthosite-Labradorite Crystals Collected by Gravity from a Gabbroic Magma	III Gabbroid Magma Differentiated to Basal Gabbro and Anorthosite	IV Anorthosite = Labradorite Collected by "Filter Press" Pressure from a Magma More Siliceous than a Gabbro
1. Inclusions of Grenville in both Whiteface and Marcy anorthosite show magmatic corrosion and assimilation		Inclusions of Grenville in both Whiteface and Marcy anorthosite show magmatic corrosion and assimilation	Grenville inclusions soaked by syenite and not by anorthosite liquids. Not much corrosion
2. Inclusions of early anorthosite in later anorthosite showing both corrosion and assimilation	Apparently not encountered and hence not discussed		Inclusions of early anorthosite in later anorthosite = early aggregates of labradorite crystals surrounded by later formed aggregates
3. Anorthosite soaked, *lit-par-lit* injected Grenville, produced anorthosite-Grenville syntectics	Apparently not recognized	Grenville-anorthosite mixed gneisses	Apparently Balk regards such soaked rocks as saturated by syenite fluids and not by anorthosite
4. Presence of anorthosite pegmatites showing that magma possessed gases	Apparently not encountered. If so, given a different interpretation	Apparently not encountered. If so, given a different interpretation	Not recognized as such but may be regarded as consolidated syenite fluids
5. Whiteface anorthosite not entirely due to differentiation, but to partial assimilation of country rock	Whiteface type an upper and outer chilled border of anorthosite	Whiteface type is an upper and outer chilled, gabbroid, border facies	Whiteface is a foliated and elongated border zone of the anorthosite massif
6. Nordmarkitic rocks show intrusive contact with anorthosite	Nordmarkitic rocks grade into anorthosite. Differentiation products of parent magma by crystal-settling through gravity	Syenite rocks show intrusive contact with anorthosite	Nordmarkitic rocks grade into the anorthosite by differentiation under pressure flowage

TABLE VII—*Continued*

7. Not all of the surrounding rock is nordmarkitic syenite but Laurentian granite	Laurentian granite does not seem to have been given proper consideration	Maintains there is insufficient evidence for the Laurentian granite	Laurentian regarded as syenite sills, in country rock. Indistinguishable from Algoman syenite
8. Nordmarkitic rocks entered while anorthosite was still hot, assimilated the latter, and produced syntectics	Transitional rocks due to differentiation	Nordmarkitic rocks entered while anorthosite was still hot, assimilated the latter, and produced hybrids, the Keene gneiss	Transitional rocks due to differentiation
9. The Placid inlier does not exist	Placid inlier based upon old state map		Placid inlier not discussed
10. Keene inlier is not entirely of nordmarkitic rocks	Keene inlier may be remnants of overlying syenite layer	Keene inlier composed of various rocks, not necessarily of overlying syenite layer	No need of an overlying syenite layer
11. Keene inlier transitional rocks are hybrids, i.e., the Keene gneiss. No field evidence for the existence of overlying sheet of nordmarkitic syenite	Keene inlier may show transitional rocks between anorthosite and syenite, due to differentiation	Keene inlier shows anorthosite-syenite assimilation products, the Keene gneiss	Transitional rocks due to differentiation
12. Algoman gabbro plugs derived from anorthosite magma cutting up through hot anorthosite		Gabbros recognized as metagabbros older than the anorthosite	Gabbros product of collection of mafic minerals in the anorthosite and formed *in situ*
13. Anorthosite, nordmarkites, and gabbros of Algoman age derived from a common magma	Anorthosite, syenite, and gabbro derived from common parent gabbroid magma	Anorthosite, anorthosite-gabbro, syenite, and syenite-granite constitute a series derived from a gabbroid magma	Anorthosite, syenite, and gabbro derived by differentiation from common parent magma more siliceous than gabbro

TABLE VII—*Continued*

Majority of Adirondack Geologists	Bowen 1917	Miller 1918	Balk 1930
I Anorthosite Injected as a Magma	II Anorthosite-Labradorite Crystals Collected by Gravity from a Gabbroic Magma	III Gabbroid Magma Differentiated to Basal Gabbro and Anorthosite	IV Anorthosite = Labradorite Collected by "Filter Press" Pressure from a Magma More Siliceous than a Gabbro
14. Intruded Grenville-Laurentian granite complex as separate intrusions	By differentiation *in situ* as now found	The anorthosite differentiated practically *in situ* from an intruded gabbroid magma	By differentiation *in situ* as now found
15. Anorthosite shows both protoclastic and cataclastic textures	Anorthosite shows protoclastic texture	Anorthosite often shows magmatic flowage	Anorthosite shows protoclastic texture, and locally magmatic flowage
16. Whiteface type may not always be foliated		Whiteface an upper and outer chill facies	Whiteface type is always foliated. Not a chill phase
17. Nordmarkite does not form a ring around anorthosite; it occurs as many separate intrusive bodies, possibly laccolithic and phacolithic in character	Syenite forms a ring surrounding or enfolding the anorthosite as a single unit	Syenite-granite series essentially a unit but later than the anorthosite, injected from below	Syenite surrounds the anorthosite as a system of irregular sills and phacoliths emerging from the anorthosite, and intruding the Grenville series
18. Syenite dikes cut anorthosite and establish age relations; the syenite is younger	Syenite dikes cut anorthosite and establish age relations; the syenite is younger	Tongues and dikes of syenite and granite definitely cut the anorthosite	Veins of syenite in anorthosite represent "mother-liquor"

structure of the anorthosite. Balk proposes a lens shape. The consanguinity of the Algoman igneous rock is held in common by all. Where we differ is in the concept of the place of origin of the anorthosite. Bowen and Balk stress the belief that these rocks originated where we see them now. The older group of geologists, however, feel that they were generated from a deep-seated parent magma and successively invaded the overlying country rock in separate units. Essentially the major question is the degree of erosion which the anorthosite and surrounding rocks have suffered. Has the place of origin been uncovered? Balk certainly feels it has, to the extent that the general lines of magmatic flowage can be traced. He is the best one to investigate this phase of the geology of the region. I cannot but feel, however, that, in his zeal to apply the theories of Hans Cloos to the Adirondacks, he has unconsciously forced field observations to fit his ideas. I likewise may have interpreted my field findings to fit my theories. We all do that.

Bowen is an advocate of magmatic differentiation through crystal settling by gravity. His articles and his recent book contain very plausible reasons for believing in this method of petrogenesis. He naturally desired to find actual illustrations of this phenomenon. He turned to the Adirondacks and has made a very real contribution. Balk postulating a magma more siliceous than gabbro allows labradorite crystals to form and by injectional pressure squeezes the mother-liquor, potentially syenite, away and does not advocate crystal settling by gravity. The older geologists regard the anorthosite as an intrusive with the usual characteristics and derived from a magma of appropriate composition. It does not seem probable that the Adirondacks illustrate crystal settling because the force of gravity in the face of pressure flowage, the cause of much of the foliation within the anorthosite, appears to be too severe. Igneous intrusion is a complex phenomenon where conflicting forces, drag friction along the walls of the channel ways, and gravity produce complex movements in the consolidating rock. Balk's work promises to unravel the history of the central Adirondacks, provided he is not too greatly influenced by the method advocated by Hans Cloos to consider the observations of geologists who have preceded him in this difficult field.

Balk's proposal offers the best solution of the original problem of the anorthosite in particular or monomineral igneous rocks in general. It was this world-wide problem that appealed to Bowen, who departed from the views of Vogt,[1] Daly,[2] and Loewinson-Lessing,[3] that anorthosite was molten as such because his studies of the albite-anorthosite system in artificial dry melts at atmospheric pressures required a higher temperature than is reasonable to regard as obtaining in nature. He sought a solution through crystal settling and looked for illustrations in the Adirondacks and in the Morin District of Canada. I feel he failed for the reason that force of gravity may be abundantly overbalanced by forces of intrusion as Balk has well shown. Loewinson-Lessing[4] concludes that he thinks that ". . . . it is more correct to acknowledge the problem of the monomineral igneous rocks and in particular the anorthosites, as not yet solved." I feel that if he had studied the problem in the Adirondacks in the field, especially with the views of Balk in mind, he would be willing to grant that Balk has proposed a very real contribution to the problem. Yet there are field and laboratory observations incompatible with Balk's interpretation:

1. Included blocks of Grenville in anorthosite appear to have been soaked by anorthositic and not always by syenitic matters.

2. The finding of anorthositic pegmatites reveals that the anorthosite contains some fluids which may have been sufficient in amount to permit the anorthosite being molten as such, a view not thoroughly considered even by Bowen.

3. There is sufficient divergent opinion regarding the foliation around the gabbros and regarding the belief expressed by the older geologists as well as by Gillson[5] and his associates that some gabbros are definitely intrusive.

[1] J. H. L. Vogt, *Kristiania Videnskapseelskap* (1908); "The Physical Chemistry of the Magmatic Differentiation of Igneous Rocks," *Kristiania Videnskapseelskap*, Vol. I (1924), pp. 52–60.

[2] Daly, *Igneous Rocks and Their Origin* (1914).

[3] F. Loewinson-Lessing, "Kritische Beiträge zur Systematik der Eruptivgesteine IV. Ueber monotektische (ungemischte) Magmen," *Tscherm, Min. Mitt.*, Vol. XX, p. 15.

[4] "The Problem of the Anorthosites and Other Monomineral Igneous Rocks," *Jour. Geol.*, Vol. XXI (1923), p. 105.

[5] Gillson, Callahan, and Millar, *op. cit.*, pp. 149–68.

4. The implication is that all the syenite-granite of Algoman age was derived from this "mother-liquor," or derivative magma. Balk attempts to explain all by a single simple theory.

5. Balk's term "syenitic" magma as the parent for the Algoman rocks is unfortunate. He means it is syenitic after the anorthosite and gabbros aggregated. Gabbroic or dioritic would to me be a much better term. Balk's "mother-liquor" is also difficult to use. In fact, the term "derivative-liquid"[1] would be much more accurate.

6. Other points frequently used in discussing the origin of the anorthosite are effective provided we all grant the particular interpretation each author holds.

On the other hand, Balk's statement that he finds occasional phenocrystic augen of labradorite embodied in syenite miles distant from the anorthosite is one of the strongest arguments in favor of his theory.

Thus, in summary, I believe that Balk has proposed a working theory that has proved very stimulating and will have far-reaching results in the studies of the Adirondack pre-Cambrian. He will fail to convince all of the Adirondack geologists, however, because he has attempted to explain complicated geology by a single simple theory. What we need is a glossary of Adirondack geological terms as used by the various workers.

[1] Balk and I are indebted to Buddington for this term.

AN AREA OF GLACIER STAGNATION IN OHIO[1]

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ABSTRACT

Evidence is presented to show that in a hilly part of Ohio the last ice sheet did not melt back with a definite front, but melted down. The drainage and relief of the region are considered briefly, and the glacial boundary across the area is described. Areas of morainic topography are present north of the glacial boundary, but the location and distribution of these are such that they are not regarded as true recessional moraines. The gravel deposits, which were laid down around ice masses left in the valleys, are described and the conditions of deposition discussed. At least one lake existed which was dammed by stagnant ice.

INTRODUCTION

When the most recent ice sheet advanced to its farthest extent in eastern Ohio, the last part of its journey was over a rugged country of considerable relief, which was also higher than the region to the north and west. The higher land in eastern Ohio had, throughout the several stages of Pleistocene glaciation, held back the ice sheets, while the lower land to the west allowed them to advance much farther south.[2]

The Wisconsin glacier in its last few miles of advance in eastern Ohio was thin and a weak erosive agent. Reaching its line of farthest advance, it retreated immediately, not by melting back along a definite front, with occasional halts marked by recessional moraines, but by melting down, uncovering the higher hills and ridges, and leaving masses and tongues of ice in the deep valleys. In the area is an absence of a terminal moraine, except in favorable localities in valleys, an almost total absence of real recessional moraines marking

[1] Published with the permission of the director, Geological Survey of Ohio.

The writer wishes to thank Mr. Wilber Stout, director of the Geological Survey of Ohio, for his encouragement and helpfulness at all stages of the investigation.

[2] G. F. Wright, Map, in "Glacial Boundary in Western Pennsylvania, Ohio, Kentucky, Indiana, and Illinois," *U.S. Geol. Surv. Bull. 58* (1890), p. 46; Frank Leverett, Map of Scioto Glacial Lobe in "Glacial Formations and Drainage Features of the Erie and Ohio Basins," *U.S. Geol. Surv. Mono. 41* (1902), pp. 340–41; J. A. Bownocker, and Others, glacial boundary on "Geologic Map of Ohio," *Geol. Surv. of Ohio* (1920).

halts of an ice front and the presence of deposits laid down by melt water over and around the masses of stagnant ice in the valleys.

The region to be described is central Holmes County, in the northeastern central part of Ohio, from the glacial boundary to the northern boundary of the county—consisting of Prairie, Salt Creek, Hardy, and Berlin townships. The area is shown on the Millersburg sheet of the United States Geological Survey, on a portion of which the accompanying map (Fig. 1) is drawn. Millersburg, the county seat, is in the central part of Holmes County, 68 miles northeast of Columbus, 67 miles south of Cleveland, and 32 miles southwest of Canton.

The area is in the western part of the Allegheny Plateau. The bed rock is mainly shale and sandstone, with thin beds of coal, clay, and limestone, of the Pottsville and Allegheny formations of the Pennsylvanian system. In the deeper valleys thin-bedded sandstones and shales of the Waverly series of the Mississippian system outcrop.

The geology of the whole of Holmes County has been studied for the Geological Survey of Ohio, but the present paper deals with the glacial boundary and the evidence of stagnation of the last ice sheet in the northern and central part of that county, because some unusual features are well shown there.

RELIEF

The region is a dissected plateau which has not yet reached middle maturity. The hills and ridge tops, which rise to an elevation of from 1,200 to 1,240 feet, are remnants of the Harrisburg peneplain.[1] Wide shelves or "berms"[2] bordering some of the valleys at an elevation of approximately 1,100 feet are tentatively correlated with the Worthington erosion level. The flood plain of Killbuck Creek is about 800 feet in elevation. The maximum relief therefore is slightly in excess of 400 feet. Since 150 feet (or more) of fill is present in Killbuck Valley, the preglacial relief or interglacial relief was in excess of 550 feet.

[1] Wilber Stout and R. E. Lamborn, "Geology of Columbiana County," *Geol. Surv. of Ohio, Bull. 28* (1924), pp. 38–40; Karl Ver Steeg, "Erosion Surfaces in Eastern Ohio," *Ohio Jour. Sci.*, Vol. XXXI (1931), p. 277.

[2] F. Bascom, "Geologic Nomenclature," *Sci.*, N.S., Vo.. LXXIV (1931), pp. 172, 173.

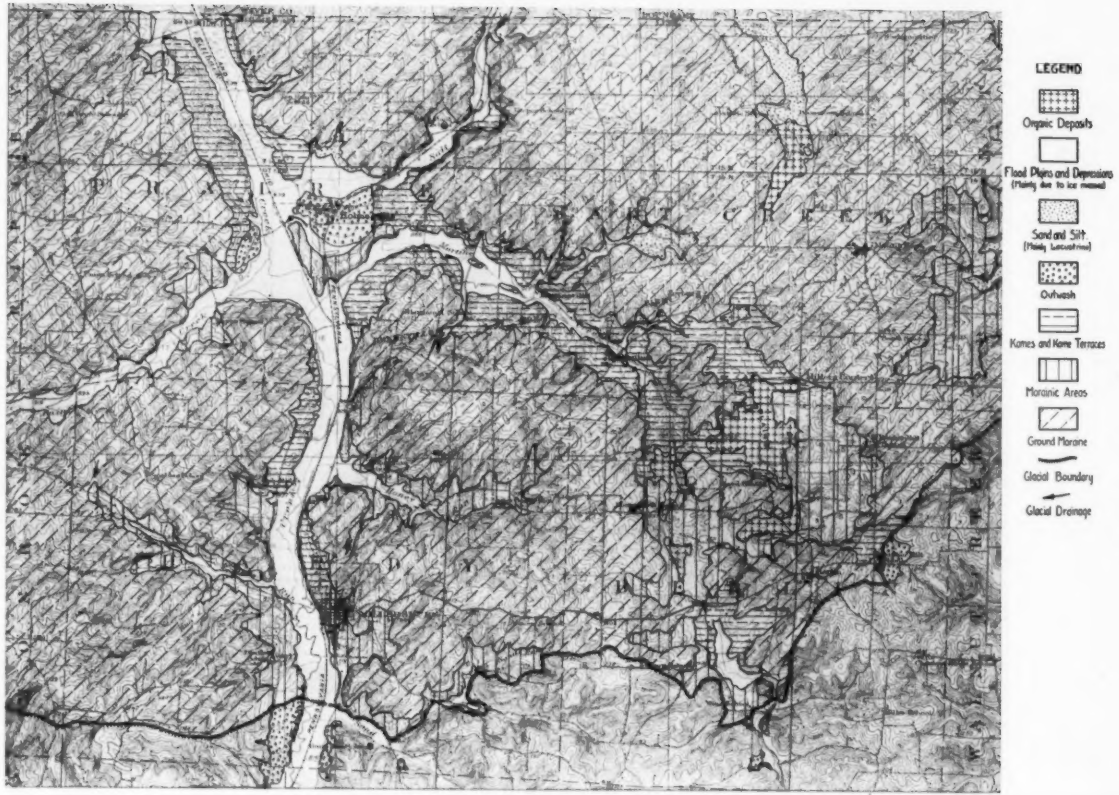

FIG. 1.—Glacial geology of central Holmes County, Ohio

The main preglacial divide,[1] between the streams flowing northward to the Great Lakes basin and those flowing south to the ancestors of the Ohio River drainage system runs more or less east and west across Holmes County at about the glacial boundary line. The present divide between the northward- and southward-flowing waters is 30 miles or more to the north. Streams between the preglacial divide and the present water shed now flow south, having been changed in their courses by the various ice sheets which invaded the state.

For some distance north of the glacial boundary the country is, in general, as rough as that to the south. The smoothing effect of the glacier as it advanced over the territory near the glacial boundary was negligible. Very little glacial erosion on the hillsides took place and the drift—ground moraine—is usually thin on the hilltops. Several miles to the north the surface becomes a bit smoother, where the ice was thicker and where its erosive action continued longer.

Into such a region the Wisconsin ice sheet advanced. The effects of the glacier are different from those in a flatter area, such as that to the north and west. The glacial phenomena are more closely allied to those found in the hilly portion of New England than to those in the more level portions of the Middle West. Some of the features in this region may be tabulated as follows:

1. Almost total absence of a terminal moraine, except across valleys.
2. Preservation of preglacial valleys and their continuance as stream courses (sometimes with directions reversed).
3. Almost total absence of real recessional moraines.
4. Preservation of the major features of preglacial topography.
5. Ice masses left in the valleys around which distinctive deposits were made.

Fig. 1.—Glacial geology of central Holmes County, Ohio

DRAINAGE

All of the run off from Holmes County eventually reaches the Muskingum River, and thence the Ohio River. The area under dis-

[1] J. H. Todd, "Preglacial Drainage of Wayne and Adjacent Counties," *Ohio Acad. Sci. Special Papers No. 3* (1900), p. 62; G. N. Coffey, "Preglacial, Interglacial and Postglacial Changes of Drainage in Northeastern Ohio with Special Reference to the Upper Muskingum Drainage Basin," *Ohio Jour. Sci.*, Vol. XXX (1930), pp. 373–84.

cussion is drained, except for a small portion in the eastern part, by Killbuck Creek and its tributaries. Killbuck Creek rises in the southern part of Medina and the northern part of Wayne counties and flows in a general southerly direction through Wayne and Holmes counties and through the northern part of Coshocton County, entering the Walhonding River near Warsaw in the latter county. Its gradient is under 2 feet per mile throughout most of its course. The present Killbuck Creek is made up in Holmes County of two parts. One of these in preglacial times flowed north from the preglacial divide mentioned, the other to the south. Evidence is accumulating to show that some of the streams in this general region, which have been reversed and now flow across the old divide, were diverted by the early or one of the early ice sheets, and that others were not diverted until the time of the latter ice sheets. Killbuck Creek is believed to have been turned to the south by one of the earlier, probably pre-Illinoian, ice sheets. The Mohican River, 12 to 15 miles west of Killbuck Creek, which also flows south through a col in this preglacial divide, is believed not to have been diverted until some glaciation succeeding that which reversed Killbuck Creek. The col in the Mohican Valley is fresh and gorge-like, whereas the col in the Killbuck Valley has been scoured out to the same width as the rest of the valley and glacial deposits are along its sides. Only by plotting in the preglacial divides and by examination of the directions of tributary streams can this col in the Killbuck be located.

Near Holmesville three large tributaries enter Killbuck Creek: Paint Creek from the southwest, Martins Creek from the southeast, and Salt Creek from the northeast. The first two, upon entering the main valley near Holmesville, turn at an angle more acute than a right angle and then proceed to the south. They are barbed tributaries.

Killbuck Creek and its two largest tributaries, Paint and Martins creeks, flow in wide level-bottomed valleys. The flood plain of the master stream is over $\frac{1}{2}$ mile wide in places. The stream flows on glacial filling which is known from well records to have a depth of more than 150 feet.

A small part of the area, central and southern Berlin Township, is drained by the headwaters of Doughty Creek, a tributary of Kill-

buck Creek which enters the latter stream south of the Holmes-Coshocton county line. Preglacial Doughty Creek headed on the south side of the main preglacial divide. The region, drained by the present headwaters, then drained into Martins Creek to the northwest. The Wisconsin glacier ponded the waters of the upper portion of the Martins Creek drainage, raising them to such a level that they cut through the divide at Troyers Mill, 2 miles south of the glacial boundary. When the ice melted away, the col had been cut deep enough to be retained as a drainage way.

A small portion of eastern Berlin Township is drained by Goose Creek and Indian Trail Creek, which flow east to the South Fork of Sugar Creek in Tuscarawas County.

GLACIAL BOUNDARY

The Scioto lobe of the Wisconsin glacier advanced farther in this area than any other ice sheet. Here no glacial deposits earlier than Wisconsin are found south of the Wisconsin glacial boundary. The last ice sheet pushed up to the top and just over the main preglacial divide mentioned previously. This high land was doubtless one of the factors which hindered the advance of the ice farther, in this part of Ohio.

The glacial boundary enters Holmes County 1 mile south of where Stark, Tuscarawas, and Holmes counties meet, extends in a general southwest direction, ½ mile south of the village of Winesburg in Paint Township, and continues to Doughty Creek, 2 miles south of Berlin. Crossing the valley of that stream, the boundary swings in a winding direction westward to Killbuck Valley 1 mile south of Millersburg, and thence due west, just on the south side of the crest of the main east-west ridge which was the preglacial divide, across southwestern Hardy Township into Monroe Township. In central southern Monroe Township the line bends to the northwest, passing across the remainder of Holmes County into Ashland County a little less than 2 miles south of Loudonville. The glacial boundary is marked by a terminal moraine only across the rather large valleys. On the ridge tops, which is the location of the major part of the boundary through here, no difference of topography gives a clue as to where the glacier stopped. The drift simply thins out and ends at

the glacial boundary. Wright[1] and Leverett[2] both consider the line to be well marked and topographically distinct. Todd,[3] however, noted that the drift ". . . . gradually thins out to the crest, creating an intervening border plain. . . . ." The actual drift border on the upland is from a few hundred yards to as much as ½ mile or more from continuous drift deposits. The intervening belt between the ending of the drift sheet and the end of the foreign boulders may have discontinuous patches of drift on it. The boundary was mapped along a line where the last boulders were found.

It is believed that the ice edge when it came up on this major divide was thin. Since it was thin it could carry very little material. It would not stand very long and would soon melt back, thus accounting for the absence of a terminal moraine on the hilltops. North of the main divide the ice would be thicker, carrying more débris, and consequently the deposits would be more abundant. A wider marginal belt of thin discontinuous drift or scattered boulders exists across Monroe, Knox, and Washington townships, of Holmes County, west of the area under discussion.[4]

At three places, two of them closely related, where the ice front stood across valleys, a terminal moraine ridge was built. A well-developed terminal moraine is present across Doughty Creek which formerly flowed to the north, but which now has its course reversed to the south as mentioned above. This terminal moraine makes a complete embankment across the valley about ½ mile long and ¼ mile wide and has diverted the upper course of Doughty Creek around it in a narrow channel. It rises about 60 feet above the floor of the valley in an arcuate form. It is made up of one continuous till and gravel ridge, and is not markedly hummocky, although a few kettle holes and shallow depressions about 10 feet deep are present on the top. Some small pockets of gravel, of sufficient volume to excavate for road purposes, are found here and there in the moraine. Only a small amount of outwash material is present in front of this

[1] *Op. cit.*, p. 60.

[2] *Op. cit.*, p. 390.

[3] *Op. cit.*, p. 63.

[4] G. W. White, "Glaciation of Northwestern Holmes County, Ohio," *Ohio Jour. Sci.*, Vol. XXXI (1931), pp. 429–53.

moraine; most of the outwash apparently was swept down Doughty Creek through the col and deposited in the valley several miles south of the glacial boundary.

From the head of Upper Sand Run to the junction of Sand Run with Killbuck Creek in southeastern Hardy Township, morainic topography is found. Along both sides of Upper Sand Run the moraine is quite well developed and is about $\frac{1}{4}$ mile wide. Irregular masses of drift fill the bottom of the valley and extend up the valley sides to an elevation of approximately 1,000 feet. The ice lay against the hillside to the south and its upper limit is well marked by deposits. From the junction of Upper Sand Run with Sand Run to the mouth of the latter stream, masses of till and gravel, very thin in places, are plastered against the north valley wall. These extend up to about 900 feet in the lower part of the valley and to about 1,000 feet in the upper part of the valley. Along the north side of the valley of Sand Run, large igneous boulders 3 to 4 feet in diameter are present on the hill slopes. They cannot be said to be thickly strewn on the surface, but they are more common here than any place north of the glacial boundary. The topographic effect of the till veneer on the valley wall is not very marked, because the ridge rises 300 feet above Sand Run. These knolls, if spread on a level surface, would not be more than 15 or 20 feet high, so spread on this inclined surface they are not very prominent. Doubtless they have slumped and slid down the hillside, and the surface is thus further smoothed. There is some question whether the ice in the lower part of the valley of Sand Run actually advanced down the hillside as far as the bottom of the valley. In the upper part of the valley the ice did advance into the bottom of the valley and across it as evidenced by marks on the south side of the valley. Evidence in the upper part of Sand Run shows that the ice front could not have been more than 200 feet thick. The elevation of the glacial boundary on the hill slope to the south is 1,100 feet at the highest and slopes rapidly down to 900 feet in the valley bottom in Section 16, Hardy Township.

Directly north of the ridge already referred to, the ice was considerably thicker. On either side of Killbuck Creek, in the valley bottom north of the mouth of Sand Run and at the south edge of the

village of Millersburg, a moraine is present. Curiously, the moraine does not extend across the valley. The flood plain is just as wide here as it is south of the moraine. This is explained by the fact that considerable melt water came down this stream—it being far larger when the glacier was melting than it is at present—and consequently the deposits in the valley were excavated to a uniform width. This morainic accumulation and the outwash extending from it to the south have been described by Wright[1] and Leverett.[2] In the southern part of Millersburg and just southeast of the corporation line along the east side of Killbuck Valley and in the valley of a small tributary stream are closely aggregated drift knolls from 10 to 40 feet in height. The few kettle holes and undrained depressions present between the knolls are shallow. None of the knolls rise much higher than 10–20 feet. The drift here is not very thick, except toward the middle of the valley. Near the sides of the valley one or two rock outcrops were seen.

Directly west from this morainic area, with the ½ mile wide flat flood plain of Killbuck Creek intervening, is another morainic area along the western side of the valley wall. Here the drift is thicker and the knobs are more prominent than on the eastern side of the valley. This area is roughly 1 mile long and ½ mile wide. The material is mostly unassorted till with a little gravel in the upper portion. From the southern end of this deposit a terrace extends to the south from Hardy Township into Killbuck Township. This terrace is from ⅓ to ½ mile wide and is made up of rather fine-grained gravel with few pebbles over 3 inches in diameter. The layers are well marked and, in the main, dip west 5°.

AREAS OF MORAINIC TOPOGRAPHY

Some of the deposits of till in the valleys north of the glacial boundary have a morainic topography and have been mapped as areas of moraine. With the exception of the Holmesville moraine they are not thought to be real recessional moraines, which were made by the standing or oscillation of the ice edge for a great length

[1] G. F. Wright, "Glacial Boundary in Ohio, Indiana, and Kentucky," *Geol. Surv. of Ohio*, Vol. III (1884), pp. 45–46.

[2] *Op. cit.*, pp. 389–90.

of time over a narrow belt, but are related to low places in the surface. They were deposited because the ice in the valleys was thicker, carrying more material, and when the ice melted there was more material to slump down. It would slump down irregularly to make these regions of morainic topography with drift knolls and small kettle hole-like depressions between.

The Holmesville moraine, a crescent-like structure almost 2 miles long and $\frac{1}{4}$ mile wide, in the center of the widest portion of Killbuck Valley, where Paint Creek and Martins Creek enter, has been previously described by Cole.[1] It is made up mainly of till with gravel intermixed, and while it shows some evidence of oscillation of the ice front when it was deposited, it might have been deposited from a large ice mass left in the wide part of the valley where Holmesville is now located.

Aside from the small moraine at Holmesville, the first continuous moraine, believed by the present writer to mark unquestionably a stand of a definite ice front over a considerable length, is the Wabash moraine[2] in northern Wayne County, 28 miles north of the glacial boundary. In the belt from the glacial boundary to the Wabash moraine in Holmes and Wayne counties, the areas of morainic topography are in the valleys, and can hardly be connected into loops marking the halts to a definite ice front. Conrey[3] has described and mapped the areas of morainic topography in Wayne County, which borders Holmes County on the north, and shows that, until the Wabash moraine is reached, the morainic areas are isolated and confined to the valleys, and do not appear as loops.

DEPOSITS ADJACENT TO STAGNANT ICE—KAMES AND KAME TERRACES

After the glacier had advanced to its farthest extent it had very little forward motion and did not melt back along a definite front. Rather, it seemed to have melted down, and the hilltops appeared above the ice sheet while ice remained in the valleys. This ice in the

[1] G. G. Cole, "The Holmesville, Ohio, Glacial Terrace and Moraine," *Sci.*, N.S., Vol. XLVII (1918), p. 469.

[2] G. W. Conrey, "Geology of Wayne County," *Geol. Surv. of Ohio, Bull. 24* (1921), p. 30.

[3] *Ibid.*, pp. 26–30.

valleys was stagnant and rotten and simply lay there as inert blocks and long masses. A similar situation in Connecticut has been described in great detail in several recent papers by Flint.[1] It is not meant here to postulate stagnation of the ice over the whole of the glaciated portion of Ohio but only in a belt north of the glacial boundary in the hilly portion of the state, across Holmes and nearby counties. The writer has studied this belt across Holmes County and has seen it in counties to the east and to the west. To the north in Wayne County the effects of stagnation of the ice are not so prominent, so that the belt is probably more than 10 miles wide but less than 25 miles wide. In the present paper the central part of Holmes County composed of Prairie, Salt Creek, Hardy, and Berlin townships is considered, since here the phenomena connected with stagnation of the ice are well shown.

As the ice in the valleys melted away, the melt water might flow off to the south, if drainage were unimpeded in that direction, or might be imponded as lakes between the ice mass in the valley and the valley wall. If the melt water flowed off to the south it would flow between the ice mass and the valley wall, and kame terraces or "ice-contact stream terraces"[2] would be built up. If water were impounded between the ice mass and the valley wall, deposits of temporary lake character would be laid down. Most of the Connecticut deposits described by Flint are regarded as ice-margin lake deposits. In the region under discussion, however, while some ice-margin lake deposits are present and will be mentioned, most of the deposits seem to have been made by streams flowing between the ice in the valley and the valley wall. The term "kame terrace" will be used for such deposits here. Similar terraces called "esker terraces" have been mentioned by Wright[3] as occurring farther north of this region in the Killbuck Valley in Wayne County near Wooster.

Probably sometimes between the ice mass and the valley wall the

[1] R. F. Flint, "Pleistocene Terraces of the Lower Connecticut Valley," *Geol. Soc. Amer. Bull.*, Vol. XXXIX (1928), pp. 955–84; "The Stagnation and Dissipation of the Last Ice Sheet," *Geog. Rev.*, Vol. XIX (1929), pp. 265–89; "The Glacial Geology of Connecticut," *Conn. State Geol. Nat. Hist. Surv. Bull. 47* (1930).

[2] R. F. Flint, "Glacial Geology of Connecticut," *op. cit.*, p. 103.

[3] G. F. Wright, "Postglacial Erosion and Oxidation," *Bull. Geol. Soc. Amer.*, Vol. XXIII (1912), p. 285.

space would not be completely occupied by drift nor by running water. In such places, deposits slumping off the ice mass would accumulate here and there as separate deposits which, as the ice left, would remain as kames. Deposits along the valley sides are of all gradations: separate kames, massed kames, and kames built so closely together that they constitute terrace-like features. Therefore, no attempt was made to separate kame deposits from kame terrace deposits on the accompanying map (Fig. 1). Both were built off and very close to the ice edge, and the water which deposited them then ran off down the valley. Some kames were built above the level of the kame terraces, giving hummocky surfaces.

The material composing these kames and kame terraces is mainly gravel, mostly arranged in fairly horizontal layers. At places the layers are cross bedded. Occasional boulders having diameters of 4 or 5 feet are present in some of the deposits. As a general rule the material in the lower part of the terraces is sandier, and in some places the lowest part is nothing but sand. Many of the terraces contain from 30 to 40 feet, in some cases more, of gravel which is of great economic value for road purposes in the region, as shown by the number of excellent gravel roads throughout the county.

The terrace masses vary in elevation, but each terrace mass slopes downstream about 20 feet per mile although there is some divergence from this figure. Since the terraces were not built at the same time, those downstream probably having been built first, it is not necessary that the downstream terraces be lower than those upstream. The terraces in the valley of Martins Creek are more continuous and exhibit a more uniform upstream increase in elevation, while those in Killbuck Valley are more divided into distinct masses and show more divergence in elevation from terrace to terrace. It is believed that the ice tongue in Killbuck Valley retreated upstream—northward—and that in Martins Creek Valley melted out more or less at the same time.

Deposits built around and beside ice blocks are found along either side of Killbuck Creek from the glacial boundary to the Holmes-Wayne county line, and in the valley of Martins Creek northwest from central Berlin Township and across the southwestern corner of Salt Creek Township into central Prairie Township, where the

valley joins that of Killbuck Creek. Smaller areas of the same sort of deposits are found in the valley of Salt Creek between Holmesville and Fredericksburg, and in the headwaters of Doughty Creek.

Killbuck Valley.—The gravel deposits of Killbuck Valley will be described from north to south. On the west side of Killbuck Valley from Rush Run, just south of the Wayne-Holmes county line, to Paint Creek, opposite Holmesville, a very hummocky terrace about 3 miles long and from $\frac{1}{4}$ to $\frac{1}{2}$ mile wide rises from 60 to 100 feet above the stream level. The till-covered uplands to the west rise from 100 to 160 feet above the terrace. This is the largest and best-developed kame terrace along Killbuck Creek in Holmes County. The elevation of the northern end is somewhat over 940 feet and that at the southern end a bit over 900 feet. While doubtless some trimming by lateral erosion of Killbuck Creek has taken place along the edges of the terrace except at the southern end, the slope in general is thought to be mostly the original ice-contact slope built up against the ice when the gravel was being deposited, modified by later slumping when the ice melted out. This ice-contact slope, preserved especially on the southern part of the terrace (Fig. 2) is somewhat ragged, with re-entrant angles where projections of the ice mass rested.

Although the surface of the terrace is fairly level in places, especially at the southern end, throughout most of its length it is very hummocky, with knobs rising above the general level 10 to 20 feet, and with many bowl-shaped kettle holes from 10 to 20 feet deep. The kettle holes perhaps are a bit more numerous near the center of the valley, or closer to the former ice edge. In the northern part of this terrace some unassorted material is mixed with the gravel. In the southern part, little or no unassorted material is present, and the upper portion of the gravel is arranged in horizontal layers. In the bottom of a gravel pit, in the southern part of Sec. 4, Prairie Township, near the south end of the terrace, the layers dip southwest about 5°.

Opposite the terrace just described a very much narrower and somewhat discontinuous terrace on the east side of Killbuck Valley extends from the Wayne-Holmes county line to the point where Salt Creek enters Killbuck Creek. From the county line to Tea Run the terrace is about $\frac{1}{8}$ mile wide. It dies out from Tea Run to a point

about ½ mile south, and then becomes gradually wider, being ½ mile wide at its southern end a little less than 1 mile north of Holmesville. This terrace is not as high as the one across the stream, varying from 30 to 60 feet above the creek.

The northern part of the terrace is made up of fairly coarse gravel with some interbedded 6-inch sand layers, especially near the bottom. On the north side of Tea Run at the state road to Wooster, 30 feet of sandy gravel containing many rounded boulders up to 1 foot in diameter are exposed. Cross bedding is prominent, and the

FIG. 2.—Ice-contact slope of kame terrace on west side of Killbuck Valley in sections 9 and 4, Prairie Township.

material was apparently deposited off the ice edge without a great deal of sorting. The southern part of this discontinuous terrace, in the southwestern part of Sec. 34 and the northwestern part of Sec. 3, Prairie Township, is a well-developed flat area rising not more than 40 feet above the flood plain of Killbuck Creek to the west. A somewhat ragged ice-contact slope is present along the stream valley. Shallow depressions—kettle holes—10–20 feet deep are common in this portion of the terrace. One or two contain tiny ponds.

The end of the terrace slopes gradually to the southeast toward Salt Creek and grades into a sandy flat. It may be that the ice in the lower part of Salt Creek melted out before that in Killbuck

Valley, and that this is an outwash apron extending to the southeast into the already freed valley of Salt Creek. The material lends support to this belief. It is coarse near Killbuck Creek and becomes progressively finer and more sandy to the southeast toward Salt Creek.

Another kame terrace on the west side of Killbuck Creek extends from the southern part of Prairie Township into Hardy Township. It is 2 miles long and about ½ mile wide at the southern end. Its elevation varies from 900 feet at the northern end to 880 feet at the southern end. The ice-contact slope has been modified by lateral erosion of Killbuck Creek, but along the northern half of the terrace the original ice-contact character is still preserved. The top of the terrace is hummocky, caused by kettle holes in the terrace rather than by kames rising above the terrace level. The kettles are wide and shallow, and few are more than 10 feet deep. No water stands in them, the water draining out through the underlying gravel. The southern part of the terrace is made up of rather coarse, cobbly gravel containing many blocks which are from 2 to 3 feet in diameter, particularly in the inner part of the terrace which rested against the ice. The remainder of the terrace to the north is made up of medium to fine gravel with a little sand intermixed.

Just south of the end of this terrace is a small area of morainic topography made up chiefly of till knolls, which rise a bit higher than the top of the terrace. It is believed that ice remained here longer than it did where the terrace was deposited and that the water, which deposited the terrace, crossed over the ice to the east side of the valley and deposited on to the south another terrace which will be described next.

The terrace mass upon which Millersburg is built extends from ½ mile north of the corporation line to the southern part of the town, a distance of 1½ miles. The top of the terrace is fairly level but the top and the slope nearest Killbuck Creek have been greatly obscured by cutting and filling and other works of man. This terrace contains masses of till, veneered with gravel. Till was probably deposited during the advance of the ice sheet and gravel deposited during the melting of the ice.

At the north end of the terrace 30 feet of poorly sorted gravel are

exposed in a pit. An occasional boulder up to 1 foot in diameter is present. Some sand layers about 1 foot in thickness and occasional silt layers a few inches thick are interbedded in the gravel. Some layers of gravel are horizontal, others dip as much as 10° east, toward the valley wall. Along the railroad which runs at the bottom of the terrace between it and Killbuck Creek, gravel is exposed. In a pit near the rubber factory, at the edge of the terrace, the gravel was seen to be fine grained at the bottom and coarser toward the top of the bank. The beds are in the main horizontal, but with some cross bedding.

Martins Creek Valley.—The valley of Martins Creek from the head to the mouth is partly filled with gravel deposits. This stream rises in northeastern Berlin Township and enters Killbuck Valley at Holmesville. At Martinsville, midway of the valley, 266 feet of valley filling was penetrated in a well. The present stream flows in a depression the width of which varies from $\frac{1}{8}$ mile to more than $\frac{1}{4}$ mile. The central depression is interpreted, not as a stream cut flood plain, but as the depression where ice rested while deposits of gravel were being banked up along its sides. In postglacial times the stream has undoubtedly smoothed the bottom of this central depression, but very little lateral cutting has been done. The elevation of the gravel deposited around the ice varies from a little over 1,100 feet at "The Plains" near the head to 920 feet at the mouth of the valley. In the latter stages of the melting of the ice in the valley all the water from the valley flowed to the northwest, entering Killbuck Creek and then flowing on to the south. Some of the water from the upper portion of the valley at the early stages of the melting out of the ice flowed into the upper part of Colliers Run through a spillway, $\frac{3}{4}$ mile southeast of Hammond School, the elevation of which is 980 feet.

In the upper part of the valley are several large swampy depressions, the largest of which is called "The Plains." These are interpreted as large, shallow kettle holes. "The Plains" (Fig. 3) is a flat area about 1 mile square, in the northern part of Berlin and the southern part of Salt Creek townships. The boundary is crooked and ragged. The depression, once a swamp, is now artificially drained, and the rich organic soil cultivated. The border of this old

swamp is particularly significant. It is surrounded on the north, west, and south by a fringe of gravel kames, shown on Figure 3. Some isolated kames are present out in the flat area near the border. The bordering kames are believed to have been deposited by water from an ice mass resting in the depression. The water flowed to the north at the northern part of "The Plains," and to the west and northwest at the western side. On the eastern side an area of morainic topography bounds "The Plains," but a very thin inner fringe of gravel is found here also.

FIG. 3.—Ice block basin of "The Plains," northern Berlin Township, looking west. Fringing kames in the distance.

The border kames are mostly 10–20 feet high, rising higher against the hillsides to the south and southeast. The kames are packed tightly together in places and kettle holes with water in them form small ponds, especially to the southwest, where the kame area is from $\frac{1}{16}$ to $\frac{1}{4}$ mile wide. The inner boundary is ragged and kettled, showing undoubted ice-contact characteristics. There has been no opportunity for lateral erosion of streams here. Because the slopes bordering depressions farther down Martins Creek have the same characteristics, they are also interpreted as ice-contact slopes.

Similar but smaller depressions with kames bounding them, at least in part, are found in the low areas to the west and to the north of "The Plains." The low area to the north is completely surrounded

by gravel knolls. The valleys of the north and south forks of Martins Creek to their junction at Benton are partly filled with kames. The kames west of "The Plains" in the south fork of Martins Creek, just south of the Salt Creek-Berlin township line, are very irregular. They rise to as much as 80 feet in height although most of them are under 40 feet. The kettle holes between are quite large, some of them being $\frac{1}{4}$ mile in diameter (Fig. 4). Apparently in these tributary valleys there was no definite drainage line established, but water

FIG. 4.—Gravel deposits laid down around ice blocks in the valley of Martins Creek (south fork), northern Berlin Township, 1 mile southeast of Benton. Note the depression—a kettle hole—bordered by ice-contact slope.

flowed between, over, and around these ice blocks and built up gravel deposits clear across the valley rather than being confined to the sides, building kame terraces. The lower part of some of the deposits is made up of laminated silt, showing that the drainage was poor and that small temporary lakes existed for a time.

From Benton to near the mouth of Martins Creek, a distance of about 4 miles, irregular and hummocky gravel deposits are found on both sides of Martins Creek. On the south side of the stream the deposits are ragged and irregular, not kame terraces, but masses of kames. On the north side, from Benton to 1 mile northwest of Martinsville, the deposits are in the form of a kame terrace. The width of the terrace varies, but is generally about $\frac{1}{4}$ mile. Its elevation at

Benton is about 920 feet. Three miles to the northwest it is 900 feet. The terrace varies from 60 to 100 feet above the present stream level. The inner slope is sharp, ragged, and kettled, and is interpreted as an ice-contact slope. The surface is very hummocky and kettle holes, some of them 20 feet or more deep, are quite common. Some are ponds, and from others the water drains out through the porous gravel, and the depressions are cultivated. The lower 20 feet or more of the terrace above the stream is fine sand. The upper part grades from fine to coarse gravel, coarser near Killbuck Creek, to the northwest of Martinsville.

The broad central depression, making the inner valley of Martins Creek, has not been excavated by the stream, as shown by the fact that from Martinsville for a little more than 1 mile to the northwest the depression has small gravelly kames rising from it even in the center near the stream. Obviously, if the stream had wound back and forth, and cut this flood plain, these gravel knolls would not exist in the center of the valley.

A mile to the east of Holmesville the terrace broadens out into a kame plain between the drift-covered rock hills to the northeast and the Holmesville recessional moraine to the southwest. Most of this plain is at an elevation of from 900 to 940 feet, although one or two knobs rise higher. The material is believed to have been deposited between a mass of ice standing in the valley of Salt Creek to the north and another back of the Holmesville moraine where the village of Holmesville is located, the water escaping to the south between the moraine and the rock hills to the southeast. A considerable area of gravel which may have been deposited by water escaping in this direction is found just across Martins Creek. Ice masses may have been covered up in the present depression of Martins Creek. This depression is narrow between the moraine and the gravel to the southeast.

LAKE DEPOSITS

The former existence of bodies of standing water in parts of Killbuck Valley is shown by the presence of laminated silt and clay interbedded in some of the gravel deposits. These lakes, held in between ice in the center of the valley and the valley wall, were small and existed but a short time. Nine feet of laminated silt and sand

underlie gravel in northern Sec. 28, Prairie Township, on the east side of Killbuck Valley.

Associated with the other materials of the Millersburg terrace, a small mass of layered clay and silt is exposed at the end of North Grant Street in Millersburg. A section measured here follows:

	Feet	Inches
Fine gravel, weathered	4	0
Sand	1	6
Fine gravel	1	3
Laminated clay, clay layers $\frac{1}{4}$ inch thick separated by $\frac{1}{64}$ inch sand layers	1	5
Sand, in thin layers	0	6
Laminated clay, sandy	0	6
Till, sandy	10	0

A larger area of lake deposits is found in NW. Sec. 9, SW. Sec. 4, and SE. Sec. 5 of Salt Creek Township, in the headwaters of a small tributary which flows southwest to Martins Creek. The head of this valley was uncovered by the ice while the lower part was still obstructed, and a lake, which existed for some time, was formed. The drainage from the lake was not over the hills around this basin but probably over the ice to the southwest, as no spillway through the hills is evident. The deposits are interesting because of their similarity to varved material where exposed along the road just north of a crossroad $\frac{3}{4}$ mile northwest of Fryeburg. They consist of horizontal layers of clay and fine sand. The clay layers vary in thickness from $\frac{1}{4}$ to $\frac{1}{2}$ inch and the sand layers from 1 to 2 inches. The total thickness exposed is more than 20 feet. The appearance of the layers strongly suggests seasonal banding, and the pairs of layers are believed to be varves.

SUMMARY

As the Wisconsin glacier advanced into the area its erosive action was weak, the ice edge was thin, and no terminal moraine was deposited, except across some of the valleys.

The areas of morainic topography to the north of the glacial boundary are located in valleys. They are not believed to represent halts of a definite ice front but are thought to be related to thicker ice in the valleys.

From evidence present in the field it is postulated that, over a belt the width of which is known to be more than 10 miles, the glacier did not retreat along a definite front but stagnated, melting from the hilltops, while ice remained as inert masses in the valleys. Around these detached masses of ice, deposits were laid down by the melt water. In some places kames were deposited at the ice edge; in others, streams flowing between the ice in a valley and the valley wall built up elongate deposits of gravel which were left as kame terraces when the ice finally melted out.

Lacustrine deposits, which exhibit banding, believed to be seasonal, show that at least one lake existed which must have been held in by ice to the south, after the head of the valley to the north had been freed of ice.

ORDOVICIAN ALTERED VOLCANIC MATERIAL IN IOWA, WISCONSIN, AND MISSOURI

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ABSTRACT

Petrographic features of the altered tuff forming a 1 to 10-inch layer near the base of the Decorah formation in Iowa, Wisconsin, Minnesota, and Missouri are much alike. The chemical composition of this meta-bentonite is similar, being composed of a clay mineral high in potash. The Missouri occurrence supports Weller's assignment of the upper shales and limestones, originally included in the Plattin, to the Decorah formation; the meta-bentonite serves as a key horizon, marking the elusive boundary between the Plattin and the Decorah formation.

INTRODUCTION[1]

Interest in the altered tuff near the base of the Decorah formation in Minnesota[2] attracted the writer to the type locality of the Decorah formation in Winneshiek County, Iowa. At the Halloran quarry in Decorah, east of the Ice Cave bridge, a 2-inch layer of buff-colored meta-bentonite is interbedded with limestones underlying shales described by Calvin[3] as Decorah. Later, accompanied by G. Marshall Kay, several sections in Iowa and Wisconsin were examined to test the continuity of the meta-bentonite and a 1 to 3-inch bed was found to persist 12 to 18 inches above the base of the Spechts Ferry member of the Decorah formation. A thicker and purer layer of meta-bentonite was found by the writer in Missouri, and it contributes to the establishment of the Decorah formation in Missouri and to a more precise limitation of the boundary of that formation. In this article are described the stratigraphic position and the character of this Ordovician meta-bentonite that it may be used by others in field problems and that the extension of the de-

[1] Hearty thanks are extended to Dr. G. Marshall Kay for placing his detailed knowledge of the Decorah formation near Dubuque at the disposal of the writer. Dr. Courtney Werner has generously assisted with the problems concerning Missouri stratigraphy.

[2] Victor T. Allen, "Altered Tuffs in the Ordovician of Minnesota," *Jour. Geol.*, Vol. XXXVII (1929), pp. 239–48.

[3] Samuel Calvin, "Geology of Winneshiek County," *Iowa Geol. Surv.*, Vol. XVI (1905), p. 86.

posit may be looked for in other localities. The Missouri occurrence will be discussed first and then it will be compared with the same layer in Iowa, Wisconsin, and Minnesota.

MISSOURI OCCURRENCE

An easily accessible exposure of the Missouri Ordovician meta-bentonite is in Jefferson County, 26 miles by road south from St. Louis University. The stratum outcrops in a ditch on the east side of United States Highway 61, 2 miles north of Pevely near the top of the hill opposite the Koch Valley School, which is shown on the United States Geological Survey topographic map of the Kimmswick quadrangle.

The accompanying stratigraphic section was made at this point.

	Feet	Inches
KIMMSWICK LIMESTONE:		
Coarsely crystalline, flesh-colored limestone containing *Receptaculites oweni*	1–3	.....
Disconformity		
DECORAH FORMATION:		
Fine-grained, buff-colored, thin-bedded limestone alternating with bluish-green shale	9	.....
Fine-grained, buff-colored, massive limestone	.....	10
Grayish, fossiliferous limestone and bluish-green calcareous shale; *Pionodema subaequata* abundant	3	.....
Fine-grained, fossiliferous, gray limestone	1	5
Bluish-green, calcareous shale	2	.....
Fine-grained, fossiliferous, buff limestone	1	.....
Bluish-green calcareous shales	1	.....
Medium-grained, fossiliferous, buff limestone	.....	10
Meta-bentonite, gray, thinly laminated with several layers of brachiopod shells separated by meta-bentonite	.....	3
Meta-bentonite, white, or yellowish-brown, poorly bedded, very plastic when wet	.....	7
Greenish shale, weathers brown	.....	4
PLATTIN LIMESTONE:		
Fine-grained, thin-bedded, buff limestone	.....	.....

At the Toronto meeting of the Geological Society of America, the writer[1] referred to the Ordovician altered volcanic material in

[1] "Ordovician Bentonite in Missouri" (abstract), *Bull. Geol. Soc. Amer.*, Vol. XLII (1931), p. 224.

Missouri as "bentonite." For the sake of uniformity in nomenclature, it seems best to employ Ross's broader term, "meta-bentonite,"[1] which includes bentonitic materials that have lost some physical properties due to alteration and metamorphism.

The meta-bentonite contrasts strikingly with the associated sediments in Missouri because of its whiteness, waxy luster, and unusual stickiness when wet. Near the top of the Koch School hill, the meta-bentonite rests on 4 inches of greenish shale, but about 800 feet down the slope along the highway the same meta-bentonite rests directly

FIG. 1.—Hammer head shows position of the white part of the meta-bentonite layer in lower beds of the Decorah formation. Near Koch Valley, Mo.

on the Plattin limestone. Presumably the shale layer is lenslike and dies out in that distance. At this latter point, 7 inches of poorly bedded meta-bentonite lie between two limestones (Fig. 1), and the upper 3 inches containing the several layers of shells given in the foregoing stratigraphic section are missing. The alternating layers of shells and meta-bentonite were probably caused after the deposition of the volcanic material by the agitation of the waves which stirred up the fine sediment and repeatedly covered each successive group of invading brachiopods.

Alternation of limestone and shale characterizes the Decorah formation, and its thickness in Missouri depends largely upon the

[1] Clarence S. Ross, "Altered Paleozoic Volcanic Materials and Their Recognition," *Bull. Amer. Assoc. Pet. Geol.*, Vol. XII (1927), p. 164.

amount which escaped erosion before the deposition of the overlying Kimmswick. Evidence that the Decorah suffered solution and erosion is clearly displayed near the top of the hill at this locality. Solution depressions in the Decorah limestone are filled with coarse, crystalline Kimmswick limestone containing fragments of *Receptaculites oweni* (see Fig. 2). The contact between the Decorah and the Kimmswick is irregular, sharp, and disconformable. As originally defined, these alternating shales and limestones were part of the Plattin formation, for the Plattin included all the strata between the

FIG. 2.—Disconformable contact of Decorah formation with Kimmswick is shown (at hammer head and arrows) in top massive layer, where irregular solution surface is filled with Kimmswick limestone. Near Koch Valley, Mo.

Joachim limestone below and the Kimmswick limestone above. Weller[1] has correlated the upper shaly beds of the Plattin containing *Pionodema subaequata* with the Decorah formation of Iowa. The writer considers the alternating shales and limestone between the meta-bentonite and the disconformity just described as a distinct formation and the exact equivalent of the lower part of the Decorah formation of Iowa, Wisconsin, and Minnesota.

The meta-bentonite may be seen along the old state road to Eureka about 2 miles south of Glencoe. It is necessary to dig along the roadside, for the shaly beds on the hill slope slump rapidly.

[1] Stuart Weller and Stuart St. Clair, "Geology of Ste. Genevieve County, Missouri," *Mo. Bur. Geol. and Mines*, Vol. XXII (2d ser., 1928), pp. 109–12.

Both white and yellow meta-bentonite of about the same thickness can be seen here. Dr. Courtney Werner has seen the same meta-bentonite near St. Albans.[1] These scattered occurrences, always at the same stratigraphic position, indicate that the meta-bentonite forms a continuous bed that may be expected wherever the lower Decorah is exposed. This idea has been expressed by Kay,[2] who has named this meta-bentonite the Hounsfield.

ORDOVICIAN META-BENTONITE COMPARED

The Decorah meta-bentonite of Missouri is thicker and purer than that of Iowa and Wisconsin, and more satisfactory material for chemical analyses is obtainable. Two samples were collected and purified by sedimentation methods, and the results of chemical analyses are given in Table I. The clay mineral of Missouri meta-bentonite is similar to montmorillonite except that it has over $4\frac{1}{2}$ per cent of potash and a lower content of water. Ross and Shannon[3] found the same to be true of the Ordovician meta-bentonite of Kentucky (see Table I, col. 5). Kerr[4] reports that the X-ray pattern of the high potash clays is different from montmorillonite, suggesting a distinct mineral in them. In this paper the clay mineral of the meta-bentonite with high potash and low water will be referred to as "potash-montmorillonite."

The refractive index β of the potash-montmorillonite composing the white meta-bentonite is 1.530 or $1.525 \pm .005$; that of the gray or yellowish-brown meta-bentonite is usually slightly higher (Table II). Two adjacent samples, one white and one yellowish brown, were collected near Koch Valley to determine the difference in composition which would account for the color and higher index of the brown. The white sample contained very fine calcite, which could not be separated, and the analysis showed 5.30 per cent CO_2 present.

[1] Personal communication.

[2] G. Marshall Kay, "Stratigraphy of the Ordovician Hounsfield Meta-bentonite," *Jour. Geol.*, Vol. XXXIX (1931), pp. 361–76.

[3] Clarence S. Ross and Earl V. Shannon, "The Minerals of Bentonite and Related Clays and Their Physical Properties," *Jour. Amer. Ceramic Soc.*, Vol. IX (1926), p. 92.

[4] Clarence S. Ross and Paul F. Kerr, "The Clay Minerals and Their Identity," *Jour. Sed. Pet.*, Vol. I (1931), pp. 59, 63.

A correction has been made for this by combining the CO_2 with sufficient CaO to form calcite, and the recalculated calcite free sample is given for comparison (Table I). The yellowish variety has 2.20

TABLE I

	1	2	3	4	5	6	7
SiO_2	50.19	52.20	50.68	51.27	53.12	54.56	54.80
Al_2O_3	20.04	20.92	17.23		18.72	19.97	22.93
FeO	.22	.16	.....	25.09	.....	1.28	.45
Fe_2O_3	.41	2.61	.....		1.12	.69	1.91
TiO_2	Nil	Tr.	.....	.....	.....	Nd.	Nd.
CaO	2.68	2.01	3.21	1.25	1.40	1.08	1.20
MgO	3.70	3.42	4.56	4.44	6.92	5.08	3.10
MnO	Nil	Nil	.....	.....	.....	.....	.....
K_2O	4.60	4.78	.....	Nd.	5.72	4.06	2.04
Na_2O	Tr.	Tr.	.....	Nd.	Tr.	1.66	4.12
H_2O at 105° C.	11.25	7.40	24.32	4.82	12.04	6.62	4.58
$H_2O+105°$ C.	6.91	6.40		7.22		5.32	5.03
CO_2	*	Tr.	.....	.....	.....	.....	.....
F	Nd.	Nd.	.....	Nd.	Nd.	.13	.11
P_2O_5	Nil	Tr.	.....	.....	.....	.15	.13
S	Tr.	Tr.	.....	.....	.....	.....	.....
Undetermined	.....	.....	.....	5.91	.....	.....	.....
Total	100.00	99.90	100.00	100.00	99.04	100.60	100.40

1. White meta-bentonite in Decorah formation, Koch Valley, Mo.—W. H. HERDSMAN, analyst. * Analysis showed 5.30 per cent CO_2 present. Sufficient CaO to combine with 5.30 per cent CO_2 to form calcite was subtracted from CaO reported and analysis recalculated to 100 per cent.
2. Yellowish-brown meta-bentonite, Koch Valley, Mo.—W. H. HERDSMAN, analyst.
3. Montmorillonite. Theoretical composition to satisfy the formula $(Mg, Ca)O.Al_2O_3 \cdot 5\ SiO_2 \cdot 8\ H_2O$ with MgO:CaO present in the ratio of 2 to 1.
4. Meta-bentonite in Decorah formation, Twin City Brick Plant, St. Paul, Minn.—R. J. LEONARD, analyst.
5. Ordovician meta-bentonite, High Bridge, Ky.—COLLECTOR, CHARLES BUTTS. Purified by CLARENCE S. ROSS, analyzed by EARL V. SHANNON (*Jour. Amer. Cer. Soc.*, Vol. IX [1926], p. 92).
6. Meta-bentonite from High Bridge, Ky.—D. F. FARRAR, analyst. (See Nelson, *Bull. G.S.A.*, Vol. XXXIII [1922], p. 614.)
7. Meta-bentonite from road cut on the Dixie Highway at Singleton, Bedford County, Tenn.—D. F. FARRAR, analyst (*ibid.*).

per cent more Fe_2O_3, and with this the color and higher refractive index are most likely connected.

In Table II, samples of the same color potash-montmorillonite from Minnesota, Iowa, Wisconsin, and Missouri have the same re-

fractive index regardless of geographic location. This would indicate that all have approximately the same chemical composition, as would be expected if they were derived from the same ash fall. An examination of the limited chemical information available (Table I) bears this out and reveals certain points of resemblance.

TABLE II

Localities of Decorah Meta-bentonite Studied	Minerals Present						
	Montmorillonite Refractive Index β	Sanidine	Quartz	Apatite	Zircon	Magnetite	Others
St. Paul, Minn.:							
Buff or brown	1.535±.005	×	×	×	×	×	×
Gray	1.523±.005	×	×	×	×	×	×
Faribault, Minn.:							
Gray	1.525±.005	×	×	×	×	×	.....
Decorah, Iowa:							
Brown	1.535±.005	×	×	×	×	×	×
Guttenberg, Iowa:							
Gray	1.530±.005	×	×	×	×	×	×
Big Springs, Wis., near Prairie du Chien:							
Brown	1.535±.005	×	×	×	×	×	×
Platteville, Wis.:							
Gray	1.532±.005	×	×	×	×	×	.....
Brown	1.535±.005	×	×	×	×	×	×
Koch Valley, Mo.:							
Gray	1.530±.005	×	×	×	×	×	.....
White	1.525±.005	×	×	×	×	×	.....
Brown	1.535±.005	×	×	×	×	×	.....
Glencoe, Mo.:							
White	1.520±.005	×	×	×	×	×	.....
Brown	1.535±.005	×	×	×	×	×	.....

Proof that the potash-montmorillonite formed from volcanic glass consists in the retention of textures characteristic of volcanic tuffs. Near Koch Valley a pumice fragment (Fig. 3*c*) has been altered to potash-montmorillonite retaining its parallel elongate visicular cavities. At Decorah, crescent-shaped shards that are often distorted are preserved (Fig. 3*a* and *b*). Sanidine feldspar, which is limited to volcanic rocks, is present in all the occurrences studied, as well as

euhedral apatite and zircon (Table II). At Koch Valley there is a notable concentration of feldspar, quartz, and heavy minerals in the

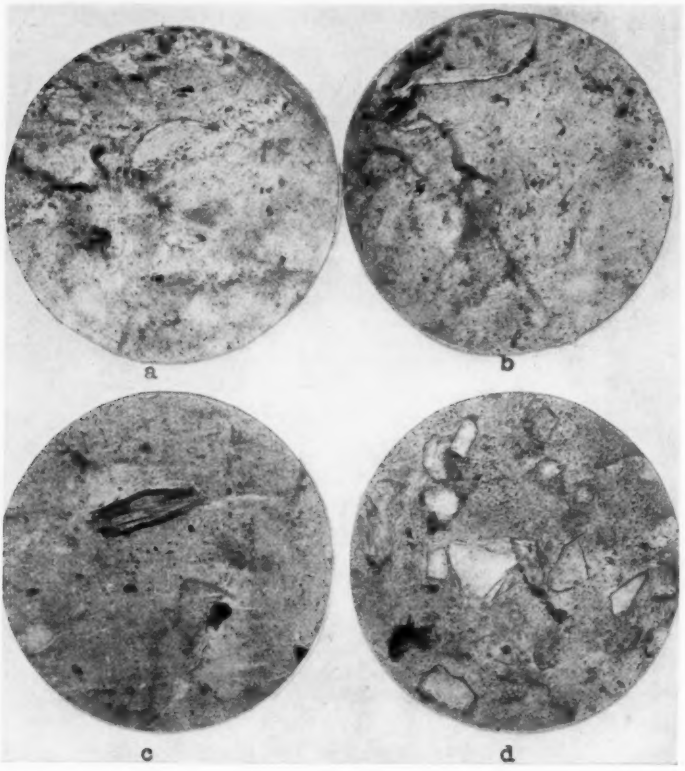

FIG. 3

a) Crescent-shaped shard altered to potash-montmorillonite in the Decorah formation at the Halloran quarry, Decorah, Iowa. ×45.

b) Distorted lune-shaped fragment now composed of potash-montmorillonite. Halloran quarry, Decorah, Iowa. ×45.

c) Pumice fragment altered to potash-montmorillonite retaining elongate vesicular structure. Decorah formation near Koch Valley, Mo. ×45.

d) Showing concentration of sanidine and quartz crystals near the base of the altered tuff. Koch Valley, Mo. ×45.

lowest part of the meta-bentonite, perhaps partly owing to the more rapid settling of the larger and heavier crystals during the volcanic eruption. The comparative abundance is brought out when an equal area of the lower part (Fig. 3*d*) is compared with one of the same size higher up (Fig. 3*c*).

Occasional rounded grains or minerals, such as garnet, foreign to a volcanic deposit, may be observed in the meta-bentonite. These were probably added by wave action during or shortly following the deposition of the volcanic material. Wave action would also account for the variation in the thickness of meta-bentonite which is thinner at Big Springs, Wisconsin, and Guttenberg, Iowa, than near Platteville, Wisconsin, and in Minnesota. Wave or current action seems necessary to account for the alternation of shells and meta-bentonite at Koch Valley already mentioned. Evidence from several lines of reasoning suggests active agitation and some re-working of the volcanic material before ordinary Decorah sedimentation was resumed.

The greater thickness of Missouri material is not due wholly to re-working, for it is freer from foreign grains than the meta-bentonite to the north. It may be that Missouri is closer to the volcano which distributed the pyroclastic ejecta. Nelson[1] has described thicker Ordovician meta-bentonites in Kentucky and Tennessee that are composed of a clay mineral high in potash (see Table I) and contain the same accessory minerals. The vent which furnished the thicker meta-bentonite of southeastern states is the most likely known source for the similar products in the Decorah formation, and all are enough alike to suggest a common derivation.

CONCLUSIONS

The petrographic and chemical features of the meta-bentonite in the Decorah formation of Minnesota, Iowa, Wisconsin, and Missouri are similar and support the assumption of having been derived from the same volcanic vent at the same time. The meta-bentonite occupies an identical stratigraphic position in larger units based on lithology and fossils in these states (Fig. 4), and adds additional evi-

[1] Wilbur A. Nelson, "Volcanic Ash Bed in the Ordovician of Tennessee, Kentucky, and Alabama," *Bull. Geol. Soc. Amer.*, Vol. XXXIII (1922), pp. 605–16.

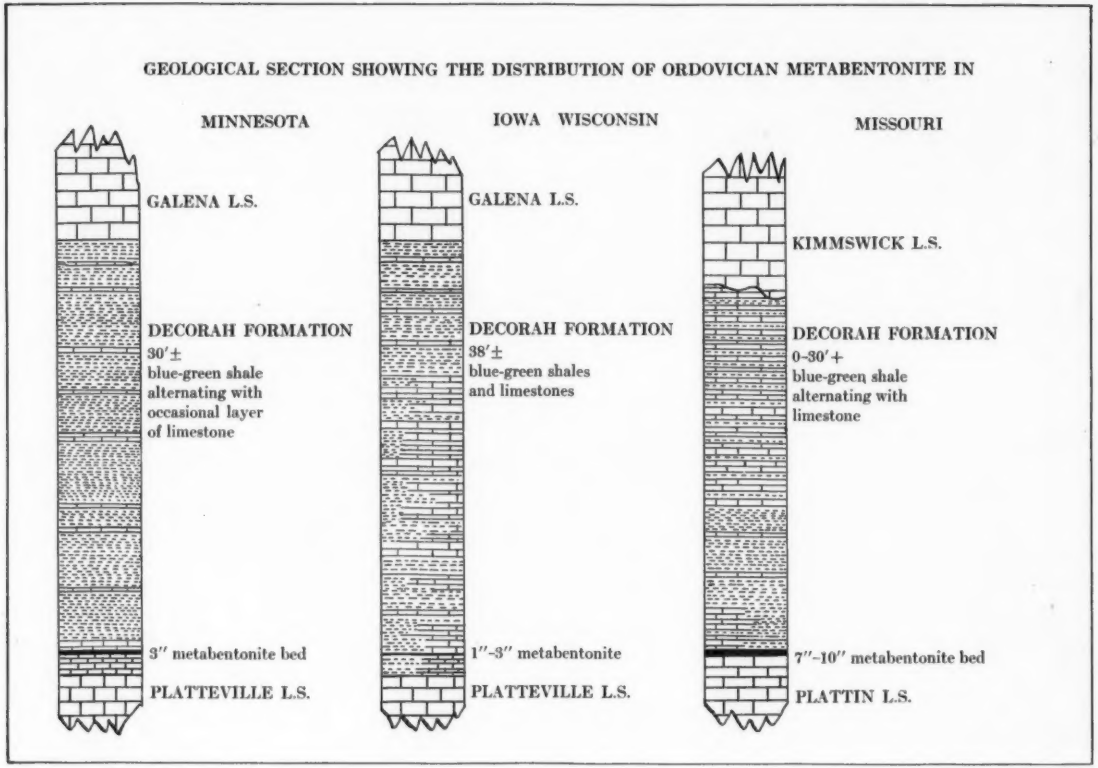
GEOLOGICAL SECTION SHOWING THE DISTRIBUTION OF ORDOVICIAN METABENTONITE IN
MINNESOTA
IOWA WISCONSIN
MISSOURI
GALENA L.S.
DECORAH FORMATION
30′±
blue-green shale
alternating with
occasional layer
of limestone
3″ metabentonite bed
PLATTEVILLE L.S.
GALENA L.S.
DECORAH FORMATION
38′±
blue-green shales
and limestones
1″–3″ metabentonite
PLATTEVILLE L.S.
KIMMSWICK L.S.
DECORAH FORMATION
0–30′+
blue-green shale
alternating with
limestone
7″–10″ metabentonite bed
PLATTIN L.S.

FIG. 4

dence verifying previous correlations. At least the lower part of the Decorah formation is represented in Missouri, and the meta-bentonite which in Minnesota, Iowa, and Wisconsin is within 12 to 18 inches from the base of the Decorah formation may be considered as the line of division separating the Decorah formation from the Plattin. The meta-bentonite, being contemporaneous throughout, is a valuable key horizon upon which detailed structural, faunal, and stratigraphic studies may be based.

FIG. 4

THE REST ISLAND GRANITE OF MINNESOTA AND ONTARIO

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ABSTRACT

This paper presents a summary of the petrology and petrography of a batholith of Algoman age. The central part of the batholith is a highly quartzose biotite-soda-granite, and the borders are shonkinite. It is concluded that the various types of igneous rock found in the batholith resulted from the differentiation of a magma. The mode of magmatic differentiation is discussed.

INTRODUCTION

It is the writer's purpose to describe a case of magmatic differentiation in a batholith of Algoman age in the Rainy Lake area of Minnesota and Ontario previously mentioned by Grout.[1] The geology of the area has been described by Lawson[2] and more recently by Grout.[3] The reader is referred to their papers for the general geologic setting. The writer visited the area in 1923 with Dr. Grout.[4]

FIELD RELATIONS

The areal distribution of the granite and shonkinite which compose the Rest Island batholith is shown in Figure 1. It will be noted that in the northern part of the area shonkinite surrounds the granite on the west, north, and east. The granite and shonkinite outcrops where well exposed on the islands are separated along part of the belt by a thin strip of mica schist, but the geographical relations lead to the conclusion that they are related rocks, the shonkinite being a border phase of the granite.

[1] Frank F. Grout, "Ages and Differentiation Series of the Batholiths near the Minnesota-Ontario Boundary," *Bull. Geol. Soc. Amer.*, Vol. XL (1929), pp. 791–809.

[2] A. C. Lawson, "Report on the Geology of the Rainy Lake Region," *Geol. Surv. Can. Ann. Rep.* (1887–88); Geology of Rainy Lake Restudied," *Can. Dept. Mines, Geol. Ser., Memoir 40* (1911), No. 24.

[3] "Couchiching Problem," *Bull. Geol. Soc. Amer.*, Vol. XXXVI (1925), pp. 351–64.

[4] Field evidence obtained by Grout since the publication of his paper indicates that the so-called Laurentian granite gneiss on Grassy Island and the Minnesota mainland is younger than the Rest Island granite, and that the "conglomerate" on northern Grassy and Review islands is a contact rock.

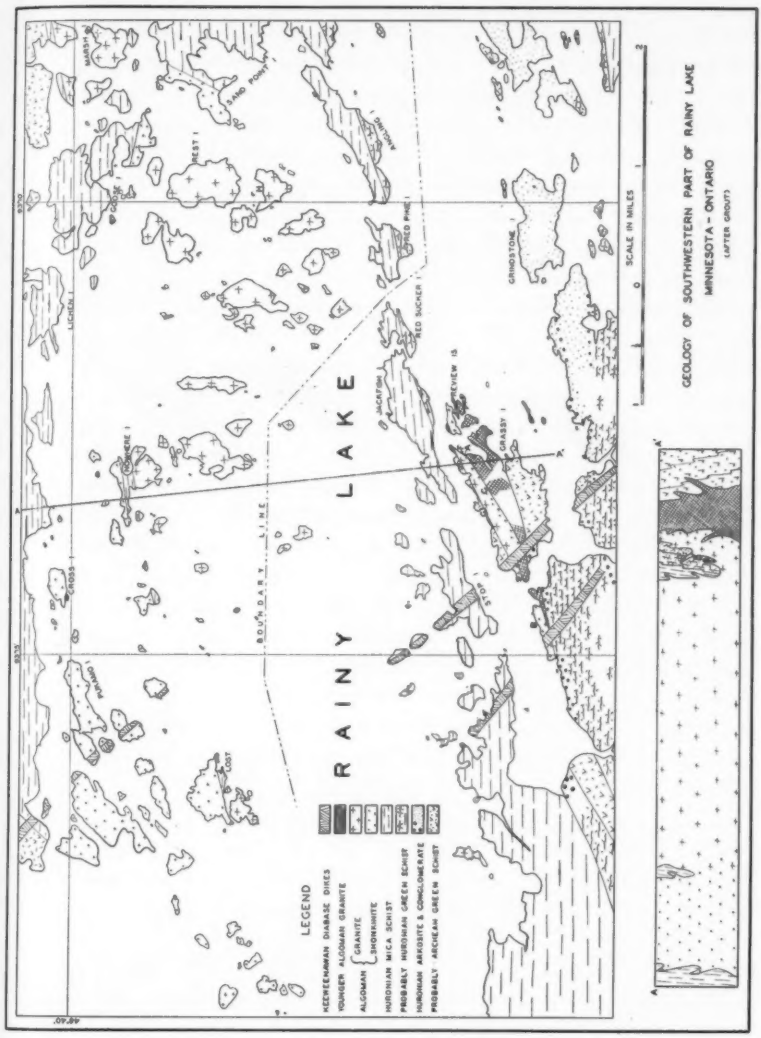
RAINY LAKE
BOUNDARY LINE
LEGEND
KEWEENAWAN DIABASE DIKES
YOUNGER ALGOMAN GRANITE
ALGOMAN GRANITE
SHONKINITE
HURONIAN MICA SCHIST
PROBABLY HURONIAN GREEN SCHIST
HURONIAN ARKOSITE & CONGLOMERATE
PROBABLY ARCHEAN GREEN SCHIST
SCALE IN MILES
GEOLOGY OF SOUTHWESTERN PART OF RAINY LAKE
MINNESOTA - ONTARIO
(AFTER GROUT)
REST I.
SAND POINT I.
RED PINE I.
RED SUCKER I.
JACKFISH I.
GRINDSTONE I.
GRASSY I.
LOCHER I.
CROSS I.
PIPARO
STOP I.

FIG. 1

The shonkinite cropping out on Review Island, Grassy Island, and the adjacent portion of the Minnesota mainland grades into granite within a few paces on the northeastern tip of Grassy Island. This gradation suggests that a gradation from granite to shonkinite also exists in the northern area, where it is obscured by poor exposures. The proximity of the Grassy Island occurrence to the granite of Rest Island and the gradation to shonkinite away from the central mass of granite suggest that the shonkinite and granite of the vicinity of Grassy Island represent the southern border of the Rest Island batholith rather than an unrelated dike. The schist separating the granite of Grassy Island from the main mass of granite and the strip of schist separating the granite and shonkinite from Nowhere Island to Lost Island are logically interpreted as roof pendants (see secs. A–A' on Fig. 1).

Briefly, the areal position of the exposures of shonkinite around the granite mass and the observed gradation from granite to shonkinite on Grassy Island leave little doubt that the shonkinite and granite are related masses, the shonkinite apparently being a border phase of the granite. The field evidence also suggests that the basic character of the border of the granite intrusive is not due to the assimilation of the schist and greenstone intruded, for on Grassy Island the Algoman granite is in contact with schist without forming shonkinite by assimilation. In the field the relationships seemed clear enough, and representative specimens of the various phases of the intrusive (locations marked with capital letters in Fig. 1) were collected for laboratory study, the results of which are set down in subsequent paragraphs.

PETROGRAPHY

Main mass of biotite-soda-granite.—Macroscopically the granite of Rest Island and nearby islands to the south and west is a gray, somewhat gneissic granite with abundant pale-blue quartz. A representative specimen (specimen H) contains oligoclase and orthoclase (54 per cent), quartz (28 per cent), biotite (11 per cent), microcline (3 per cent), epidote (3 per cent), and small quantities of apatite, zircon, magnetite, hornblende, titanite, limonite, kaolin, and leucoxene. Zoned oligoclase is the predominant feldspar, and the rock is very fresh.

Biotite-soda-granite of Grassy Island.—Macroscopically the granite from Grassy Island appears to be a gneissic biotite syenite. The average mineral composition of specimens F and G is: feldspar (50 per cent), biotite (27 per cent), quartz (15 per cent), hornblende (7 per cent), accessories and alteration products (1 per cent). The feldspar is predominantly plagioclase, probably albite or albite-oligoclase as indicated by the analysis of F (Table I). There is only about half as much potash feldspar as in the main mass of granite, and microcline is absent. The rock a few paces from the shonkinite border phase contains 14 per cent of hornblende, but that farther away from the border is without hornblende. Small amounts of zircon, rutile as sagenite, and apatite are accessory minerals. The rock is distinctly more altered than the main mass. The plagioclase especially is highly epidotized and kaolinized, and hornblende is somewhat altered to chlorite.

Shonkinite.[1]—Macroscopically the shonkinites of Grassy Island and vicinity are dark-colored, fine- to medium-grained, slightly gnessic rocks composed mainly of hornblende with some feldspar and biotite and apparently no quartz. The average mineral composition of specimens A, B, and C is: hornblende (49 per cent), feldspar (30 per cent), biotite (14 per cent), quartz (6 per cent), accessories and alteration products (1 per cent). The feldspar is predominantly plagioclase. It is albite in specimen A, and albite-oligoclase or oligoclase in specimens B and C. The accessory minerals are apatite, titanite, rutile, magnetite, and zircon. The alteration products are sericite, kaolin, epidote, leucoxene, chlorite, and uralite. Specimen A contains more hornblende (77 per cent) and less biotite (4 per cent) and feldspar (13 per cent), and is coarser grained and less gneissic than specimens B and C.

Specimen D from the northwest part of Sand Point Island is a medium-grained gneissic rock containing hornblende (46 per cent),

[1] The writer extends the term "shonkinite" to include all those phanerites containing over 50 per cent mafic minerals with orthoclase, acid to medium plagioclase, and very little quartz. Weed and Pirsson (*Bull. Geol. Soc. Amer.*, Vol. VI [1895], pp. 389–422) defined a shonkinite as "a granular, plutonic rock consisting of essential augite and orthoclase, and thereby related to the syenite family. It may be with or without olivine, and accessory nephelite, sodalite, etc., may be present in small quantities." Later they state that augite should exceed orthoclase (*Amer. Jour. Sci.*, December, 1895, p. 479).

feldspar (35 per cent), biotite (13 per cent), quartz (4 per cent), epidote (2 per cent), the accessories pyrite, apatite, and zircon. The predominant feldspar is zoned plagioclase with andesine centers and more acid outer zones. In general this rock is quite similar to the shonkinites of Grassy Island except that it contains a more calcic feldspar which occurs in larger masses. A partial analysis (Table I, D) brings out this similarity, but also shows that the Sand Point rock is a little higher in potash than that on Grassy Island.

ANALYSES

The chemical analyses of the rocks under discussion confirm the petrographic observations and bring out clearly the trend of differentiation. The analyses of the biotite-soda-granites are similar to analyses of granites of Algoman age from the Hopkins Bay area of Rainy Lake (Table I, Y) and from Burntside Lake (Table I, V). The granites contain less SiO_2 and K_2O and more Fe_2O_3, FeO, MgO, and CaO than the Vermilion granite (Table I, W). The analysis of the shonkinite (specimen A) resembles closely that of a diorite or gabbro (Table I, X), and the shonkinite border phase of the Vermilion granite (Table I, Z).

DIFFERENTIATION

Field series.—The gradation from granite to shonkinite on Grassy Island and the inferred gradation from granite to shonkinite in the northern part of the area under discussion have been discussed. In the field it is apparent that the granite on Grassy Island is an intermediate rock between the highly quartzose granite of Rest Island and the shonkinite, being more nearly a syenite. It has also been stated that marginal assimilation can scarcely account for the shonkinite border phase, for on Grassy Island the Algoman granite is in contact with schist without sign of assimilation. The field relations indicate that the different types of igneous rocks are probably due to differentiation of a magma.

Mineralogic series.—The petrographic study brings out clearly the gradation from granite to shonkinite noted in the field. Briefly, the gradation from biotite-soda-granite to shonkinite is marked by the decrease in the quantity of feldspar, quartz, and biotite, and the increase in the quantity of hornblende and possibly apatite and titan-

ite. The decrease in the percentage of feldspar is accompanied by a decrease in the ratio of potash feldspar to plagioclase. The concen-

TABLE I

ANALYSES OF PHASES OF THE REST ISLAND GRANITE AND OF ROCKS USED FOR COMPARISON

	A	F	H	D	T	U	V	W	X	Y	Z
SiO_2	53.01	66.61	67.47	52.13	52.46	57.17	68.54	71.73	52.28	68.62	58.55
Al_2O_3	9.55	16.18	15.91	.....	16.77	16.57	17.89	14.76	10.66	15.70	12.56
Fe_2O_3	2.51	.90	2.13	1.78	3.92	2.91	1.77	.58	3.05	1.66	1.72
FeO	7.28	2.75	1.78	5.51	5.44	4.54	.52	1.35	4.81	1.77	5.05
MgO	12.14	1.71	1.37	.....	5.20	4.03	1.22	.62	11.58	1.28	8.63
CaO	8.89	3.61	3.93	.....	6.23	5.36	4.02	1.18	9.75	3.56	7.34
Na_2O	2.85	5.81	4.48	3.09	2.58	3.66	5.14	3.58	2.42	5.08	3.09
K_2O	.97	1.49	2.84	1.61	1.39	1.42	1.05	4.63	1.43	1.31	2.01
H_2O	.44	.80	.36	.....	3.28	2.45	.46	.64	1.35	.56	.50
H_2O	.12	.08	.04	.....	.....	.....	.18	.20	.37	.10	.12
CO_2	.20	Tr.	.....	.....	2.14	.71	.....	N.d.	.09	Tr.	.....
TiO_2	.89	.30	.30	.....	.45	.40	.20	.53	.92	.26	.51
ZrO_2	.06	.10	.....	.....	.....	.....	None	.06	.....	.....	.03
P_2O_5	.58	.45	.....	.....	.16	.26	Tr.	.14	1.44	.10	.14
FeS_2	.....	.....	.....	.....	.....	.....	.....	.06	.....	.....	.....
S	.....	Tr.	.....	.....	.....	.....	.06	.....	.12	.03	.04
Cr_2O_3	.16	.01	.....	.....	.....	.....	None	.02	.....	.....	.09
MnO	.14	.09	.....	.....	.....	.....	.....	.03	.....	.07	.17
BaO	.....	.....	.....	.....	.....	.....	.....	.14	.....	.02	.08
SrO	.....	.....	.....	.....	.....	.....	.....	N.d.	.....	.....	.02
	99.69	100.89	100.61	.....	100.02	99.48	101.05	100.25	100.27	100.12	100.65

A. *Shonkinite.*—NE. Grassy Island, Rainy Lake; Sec. 19, T. 71 N., R. 22 W.—IRA H. CRAM, analyst.

F. *Biotite-soda-granite.*—NE. Grassy Island, Rainy Lake; Sec. 19, T. 71 N., R. 22 W.—IRA H. CRAM, analyst.

H. *Biotite-soda-granite.*—Island south of Rest Island (Canada).—IRA H. CRAM, analyst.

D. *Shonkinite.*—NW. Sand Point Island (Canada).—IRA H. CRAM, analyst.

T. *Average chemical composition of the basic Keewatin greenstones.*—CARL ZAPFFE, *Econ. Geol.*, Vol. VII (1912), p. 149.

U. *Combined analyses* of one part F and two parts T.

V. *Granite gneiss.*—Portage from Burntside Lake to Little Long Lake.—DOUGLAS MANUEL, analyst; F. F. GROUT, "The Geology and Magnetite Deposits of Northern St. Louis County, Minnesota," *Minn. Geol. Surv. Bull. 21* (1926), p. 29.

W. *Vermilion granite.*—NW. part of Sand Point Lake; Sec. 12, T. 68 N., R. 17 W.—F. F. GROUT, analyst, *ibid.*, p. 48.

X. *Gabbro.*—Odenwald, Germany.—G. KLEMM, *Nb. Ver. Erdk.*, Vol. XXVII (1906), p. 15.

Y. *Banded gneiss.*—North side of Hopkins Bay, Rainy Lake, near contact with mica syenite gneiss.—M. F. CONNER, analyst; A. C. LAWSON, *op. cit.*, p. 93.

Z. *Shonkinite.*—Near shore of Vermilion Lake, Minn.; Sec. 30, T. 63 N., R. 16 W.—F. F. GROUT, analyst, *op. cit.*, p. 48.

tration of felsic minerals in the granites and the concentration of mafic minerals in the shonkinites are shown graphically in Figure 2.

The percentage of felsic constituents of each rock corresponds closely to the distance from the border of the intrusive; specimen A is very close to the border, specimens B and D are within the border phase, specimen F is only a few paces from specimen A, specimen G is still farther from the border, and specimen H is the main part of the intrusive. As shown in Figure 2, the decrease in felsic constituents is accompanied by an increase in the percentage of hornblende and a decrease in the percentage of biotite. Hornblende is thus concentrated in the shonkinites and biotite in the granites. Specimen F is the only sample of granite containing a considerable percentage of hornblende, and forms a connecting link between the shonkinite and the main mass of the intrusive. This should be expected because of the location of specimen F very close to, and grading into, the shonkinite.

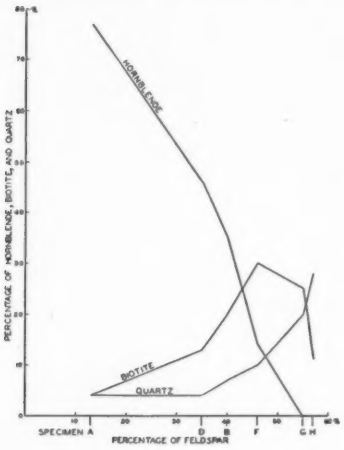

FIG. 2

Chemical series.—The analyses substantiate the gradation from granite to shonkinite. In general there is a decrease of SiO_2, Na_2O, and K_2O, and an increase of Fe_2O_3, FeO, MgO, CaO, TiO, MnO, P_2O_5, and Cr_2O_3 in the series from granite to shonkinite. The greatest percentage of K_2O is found in specimen H, and the greatest percentage of Na_2O is found in specimen F confirming petrographic observations (see Table I). The ratio of Na_2O to K_2O is more regular than the simple percentages, decreasing from border to center.

Process of differentiation.—Crystal settling, assimilation, filter pressing, mixing of magmas, diffusion, syntexis, immiscibility, convection, gaseous transfer, and Soret action are suggested by authors as processes operative in differentiation. The primary magma is thought to be about basaltic in composition. Ideally the differentiation of this basaltic magma would result in the following rock series: peridotite, olivine-gabbro, diorite, quartz diorite, grano-diorite, and

granite.[1] The shonkinite of the Rest Island batholith has about the same composition as a gabbro (cf. analyses A and X, Table I) but more basic rocks are absent. The magma from which the Rest Island batholith differentiated may have differentiated considerably on its way up before reaching the present position of the batholith. The following paragraphs suggest a mode of differentiation by which the various types of rocks described may have been formed.[2]

Marginal assimilation cannot be considered a dominant process in the formation of the shonkinitic border phase of the Rest Island batholith. As stated above, the field relations do not favor the idea of much assimilation and it is quite impossible from a chemical standpoint to account for the shonkinite by assimilation. Analysis U of Table I, which is calculated from one part of specimen F with two parts of greenstone, is lower in iron, magnesia, and lime, but is higher in alkalies, silica, and alumina, and lime predominates over magnesia. By combining analyses of granite and biotite schist no result can be obtained that is more like the actual shonkinite. In silica content the shonkinite and greenstone are very similar (cf. analyses A and T, Table I).

From the petrographic study of the rocks of the Rest Island batholith it is concluded that the probable order of crystallization of the essential minerals was: hornblende, biotite, plagioclase, potash feldspar, quartz. Some of the biotite and quartz may have been formed during regional metamorphism. As each mineral crystallized out during the cooling of the magma, the residue of the magma became more and more siliceous. Inasmuch as cooling was from the border inward, the minerals first to form were concentrated in the border phase, and the minerals last to form were concentrated in the central part of the batholith. Thus hornblende was concentrated in the shonkinite, and potash feldspar and quartz in the granite which forms the main part of the intrusive. The hornblende-biotite ratio and the feldspars need further discussion. As the mass cooled relatively rapidly at the border, hornblende was formed and held due to the increasing viscosity. Farther away from the border where crys-

[1] N. L. Bowen, "Later Stages in Evolution of Igneous Rocks," *Jour. Geol.*, Vol. XXIII (December, 1915), Suppl., p. 77.

[2] For the description of the process of a similar case of differentiation see Grout, *Minn. Geol. Surv. Bull. 21* (1926), pp. 47–52.

tallization was slower and the magma less viscous any hornblende that was formed either settled out or reacted with the magma to form biotite. The percentage of hornblende thus decreases rapidly toward the center of the batholith and biotite increases. In the very center of the batholith the percentage of biotite decreases evidently because by the time the center of the batholith cooled differentiation had proceeded so far that little FeO, Fe_2O_3, and MgO were left for the formation of biotite. Theoretically the first plagioclase to form should be more basic than the average plagioclase of the rock series, and should remain basic unless it remains in the sphere of action and is converted by the changing magma into a more acid variety. In accordance with this theory andesine with oligoclase borders is present in the shonkinite of Sand Point Island, and oligoclase is found in the granite on Rest Island. However, the shonkinite of Grassy Island does not contain a more basic plagioclase than the granite but rather a more acid variety of the same. It may be that any andesine formed in the shonkinite of Grassy Island reacted with the magma before solidification, and was changed to a more silicic type, whereas in the case of the shonkinite of Sand Point Island solidification took place before the andesine had time to become completely changed to oligoclase. The concentration of potash feldspar and quartz in the central mass of granite is in accordance with the late crystallization of both minerals.

KANSAS LACCOLITHS: A CORRECTION

KENNETH K. LANDES

Through a misunderstanding of statements made by Professor Dake in 1928 in regard to the age of the granite outcrop at Decaturville, Camden County, Missouri, I inserted the following sentence in "Kansas Laccoliths" published by G. L. Knight and me in the January–February issue of the *Journal of Geology:* "C. L. Dake has recently expressed the opinion that this pegmatite body is the top of a pre-Cambrian knob." Professor Dake informs me that this igneous body is Cambrian instead of pre-Cambrian and requests that I quote the following from an earlier paper: "At Decaturville the Gasconade is slightly arched and rests across vertical beds believed to be Bonneterre and Davis. The deformation seems to be closely related to the intrusion of a granite boss which is thus dated as post-Davis and pre-Gasconade."[1]

[1] C. L. Dake and Josiah Bridge, "Early Diastrophic Events in the Ozarks' (abstract), *Geol. Soc. Amer. Bull.*, Vol. XXXVIII, No. 1 (March 30, 1927), p. 158.

REVIEWS

Discussion on the Validity of the Permian as a System. By BERNARD SMITH, D. M. S. WATSON, R. L. SHERLOCK, C. T. TRECHMANN, J. W. GREGORY, G. A. HICKLING, W. S. BOULTON, H. C. VERSEY, P. F. KENDALL, and E. NEAVERSON. British Association for the Advancement of Science, Bristol Meeting. London, 1931. "Sectional Transactions," pp. 315–25.

The Permian is the period of problems. Few times in the well-recorded history of the earth have been characterized by such critical happenings as the closing stages of the Paleozoic. Diastrophism of the most pronounced sort, glacial climates of surpassing intensity, the extraordinary development of red beds throughout the globe, and profound biologic changes combined in climacteric fashion to make this a time of striking events and difficult problems.

The Hercynian revolution of the Pennsylvanian converted large areas of shallow sea into land and uplifted extensive tracts in various parts of the globe into lofty mountains, which together were instrumental in bringing on diversified, continental climates of unsurpassed severity and which, in turn, led to extinction of many forms of life and a radical modification of others to meet the altered conditions. This chain of consequences was of the most far-reaching sort, and the full sequence of events occupied a long period of time. The changes were slow in the aggregate, though profound. They started with the great orogeny in Pennsylvanian time and lasted in milder form into the Triassic. The intervening time of stress and storm, during which these interrelated events took place, is the Permian, or Permo-Carboniferous. It was emphatically a time of transition, from the mid-Pennsylvanian to the Triassic, from the Paleozoic to the Mesozoic, from ancient to medieval life.

Shall this long time of transition be considered a regular geologic period, and, if so, shall it be placed in the Paleozoic or in the Mesozoic? If not an independent period, shall it be added to the Carboniferous or to the Triassic, or shall it be divided among the two? To the reviewer, these seem to be the ultimate questions, though in no sense new, which have led to the present discussion arranged by the General Committee of Section C of the British Association.

Dr. Bernard Smith opens the symposium with a discussion of what properly constitutes a geologic system. He believes that so far as thickness of strata is concerned, there is ample room for a Permian system but, failing to find signs of much unconformity between the Permian and the Trias of England, he states that

it would be, indeed, a great convenience to British geologists if we could consider the rocks deposited after the zenith of the Hercynian movement in this country as belonging to the Mesozoic, and if we could combine the Permian and the Trias into one system; . . . To my mind the evidence for establishing the validity or otherwise of the system does not occur in this country.

According to Professor Watson:

The validity of a system depends on its usefulness; and this on the length of time it represents as judged from thickness of strata and from the extent of evolutionary change which takes place within it. . . . . The evolutionary change which is shown by a comparison of the reptiles and amphibia of the U. Permian Cisticephalus zone with those of the L. Permian of Texas is very great indeed, vastly more important than that which distinguishes the Stephanian from a Lower Carboniferous fauna and at least as great as that which occurs during the Trias. . . . . Thus it is probable that the Permian system represents a space of time as long as Carboniferous, and it is therefore convenient to maintain it.

Dr. Sherlock favors a division of the Permian, placing the lower portion in the Paleozoic and the upper in the Mesozoic.

The reason for the different views is that the Permian consists of a lower division normally conformable to the Carboniferous and containing Paleozoic forms of life; and an upper division conformable to the Trias and containing, besides residual forms, Mesozoic animals and plants. The supporters of the Permian system believe it to contain a fauna and flora intermediate in character between Paleozoic and Mesozoic types. This is mainly due to adding together the totally different lists of forms from the lower and upper divisions and so arriving at a passage fauna and flora.

He points out an unconformity between the Rothliegende and Zechstein. He emphasizes also the upper Carboniferous age of the glacial beds in South Africa, Australia, and South America.

As regards the Permian flora, according to E. Weass, if the division between Paleozoic and Mesozoic was made in the plants it would be placed between the Rothliegende and the Zechstein.

Dr. Trachmann:

There seems no reason to do away with the Permian so far as north-eastern England is concerned, as it is a formation quite distinct from the Carboniferous below and the Trias above. The Permian fauna is a very distinct one and has

apparently only one fossil, Spiriferina cristata, common to the Carboniferous, and none to the Trias.

Professor Gregory:

The question does not depend on British stratigraphy but on that of countries where the system is better represented and especially by marine faunas. Modern opinion appears in favor of the system from three main lines of evidence. First, the great advance in life. The flora is marked by a great development of gymnosperms, but is nevertheless pre-Triassic. The fauna shows a great advance in several groups [the foraminifera, first true ammonites, and appearance of the main division of Acanthopterygian fish]. The reptiles, as Prof. Watson in his speech has shown, are alone sufficient to make the Permian as a valid and important system.

Gregory thinks inclusion of the Permian in the Carboniferous would make that system too cumbrous.

Professor Hickling finds nothing to indicate a Permo-Triassic break in the British Isles.

The Permian and Trias together cover one great epoch of widespread continental extension. The great length of this interval is amply attested by the enormous evolutionary progress which occurred within it. . . . . It is clearly the enormous contrast between the floras and faunas above and below these rocks which led to the conclusion that the break between the Paleozoic and Mesozoic must lie within them. The contention that these rocks should form one system would be logical, and open to objection only on the ground that the system would be unwieldy. Their union, however, would do nothing to diminish the difficulties of correlation which gave rise to this debate, but would merely hide them under a comprehensive name.

Under these circumstances, he thinks close adhesion to the original definition of any system is the only alternative to chaos.

To Professor Boulton the question appears international in scope and such as can only be satisfactorily decided by some representative international body of geologists. He believes "the wise and safe course to pursue is to keep the Permian system in being, at any rate until there is a demand among the Permian specialists of the world for its suppression."

Dr. Versey suggested:

The difficulties in fixing limits to the Permian system and in correct correlation between marine and continental developments can be overcome by adopting a new basis of correlation and redefining the system accordingly. The various episodes or phases of the Hercynian revolution are all of sufficiently widespread character to afford reliable criteria for correlation, accompanied, as they are, by important faunal and floral changes. The Sudetian and Asturian phases are both used as limits to major divisions in the Carboniferous. The generally ac-

cepted beginning of the Permian period, i.e., at the Autunian, is not accompanied by any earth movement while the Autunian is so closely allied, lithologically and florally, to the Stephanian that it seems desirable to group them together as the highest major division of the Carboniferous. After the Autunian (Lower Rothliegende) the Saalian episode is shown by extensive unconformities and floral changes, so that a natural base is provided for a new system, with a flora of more Mesozoic aspect. . . . .

A further episode of movement (the Pfalzian or Palatine) occurred after the upper Permian, and where this occurs, a natural boundary between Permian and Trias. This is found in the Urals, Donetz basin, Vosges, Pyrenees, Northern England, but is everywhere weak. . . . . The Permian system is thus redefined to include only upper Rothliegende and Zechstein.

Professor Kendall:

While there appears to be no unconformity between Permian and Trias, sections in East Lancashire and Cheshire afford clear proof of a formidable inter-Permian unconformity. . . . . If the two conglomerates are identical in age, it would bring the Western succession into parallelism with the Eastern and would further render Dr. Sherlock's correlation superfluous.

Dr. Neaverson points out that the British Permian strata, as well as those of Northwestern Europe generally, are of unusual type. As present stratigraphical classification in general is made by means of the marine invertebrate faunas, he thinks that the Permian system should be redefined by means of the marine invertebrate faunas, which we know chiefly from Sicily, India, Timor, and Texas. These fossil assemblages, he thinks, justify retention of the Permian system.

Much difference of opinion has been expressed by these ten geologists, though the views are based primarily on the stratigraphy of Britain and adjacent portions of Europe which, as some of them recognize, is hardly representative of the globe. In general they reflect the needs of the practical stratigrapher much more strongly than the broader philosophical aspects of the problem. The great Hercynian revolution in the middle of the present Pennsylvanian, quickly followed by extraordinary glacial climates in the later Pennsylvanian, was of the greatest importance in bringing on the change from ancient life to medieval life. The biologic response to these exceptional physical conditions is rightly to be regarded as of prime consequence, but is it, after all, of greater importance than the chain of physical events which produced it? The decimation of the old order of life and the inauguration of the new really started with the Hercynian revolution and the adverse climates. But, as stated before, the processes of elimination and readjustment extended through a considerable span of time. The preferred line of division between the Paleozoic

and Mesozoic therefore hinges upon the question: Shall the new era commence with the climacteric expression of the underlying physical phenomena and the beginning of the biologic response, or shall it start only when the biologic response has progressed so far that the fauna and flora have become radically different from those which preceded? Shall the chain of transitional events be hooked on to the previous era as its dying phase, or shall it belong to the new era as its inauguration? Or shall it be divided between them? These fundamental questions received little consideration in the symposium.

General paleontological practice is to place greater emphasis on the appearance of new forms than on the disappearance of lingering forms of old life. On this basis, it might be suggested that the Paleozoic end with the completion of the strong phase of the Hercynian diastrophic revolution, which ended "the good old days," and that the hard times which followed, filled with readjustments, adaptations to changed conditions, and the development of new types are in truth the inaugural phase of the Mesozoic. In this case the Carboniferous or Pennsylvanian would end with the deformation at the close of the Westphalian according to present correlation. The Permo-Carboniferous period (to use the present Southern Hemisphere term) would start with the Stephanian and its glaciation. As the authorities participating in the discussion recognize a more important break within the present Permian than between the Permian and Triassic, it may be that the most logical termination of the Permo-Carboniferous period is at the Saalian deformation episode after the lower Rothliegende. In the Eastern United States the Appalachian revolution occurred after the Dunkard (lower Rothliegende) though it is not yet certain just how soon after the Dunkard it actually took place. Should the Appalachian revolution prove to be equivalent to the Saalian episode in Europe, it would be strong additional reason for placing a division between periods at this time. As a logical working hypothesis it may be suggested that the Pennsylvanian period close with the main episode of the Hercynian revolution (end of Westphalian), that the Permo-Carboniferous period comprise the time from that deformation to the close of the Saalian episode (or Appalachian revolution), and that what remains of the present Permian after that be included in the Triassic, to which it is closely related.

Conservatism and the great inertia to be overcome will probably militate against introducing such radical departures from present classification in the immediate future, but perhaps ultimately reclassification along some such lines may be accomplished. Perhaps paleontologists will prefer to move the Paleozoic-Mesozoic boundary only back to the close of

the Permo-Carboniferous period, as here defined, rather than to its beginning, and to regard the Permo-Carboniferous as a transition period. That would seem at least a step in the right direction. But, from the philosophical standpoint, the most natural division between the Paleozoic and the Mesozoic would seem to the reviewer to come with the climax of the Hercynian diastrophism, which started the new order of things. The strikingly rapid development and deployment of reptiles, characteristic of what, for want of a better name, we are calling the "Permo-Carboniferous period," would then fall in the Mesozoic, making that era, in the truest sense of the expression, the "Age of the Reptiles."

R. T. C.

Physiography of Western United States. By N. M. FENNEMAN. New York: McGraw-Hill Book Co., 1931. Pp. xiii+534.

The first volume of the long awaited physiography of the United States has appeared under the title given above. The distinguished author is chairman of the Committee on Physiographic Provinces of the Association of American Geographers, which, in association with the U.S. Geological Survey, has laid down for us a classification of the varied land forms of our country. The provinces and sections of this classification have been recently revised (*Annals Assoc. Amer. Geogr.*, Vol. XVIII, 1928). The ten provinces of the western part of the country, beginning with the Great Plains, form the subject matter of the book.

A chapter is devoted to each province and the treatment is orderly, beginning with a summary description and orientation and concluding with a physiographic history of each area. To many chapters there are added notes on the mineral resources and other pertinent matter suggesting the relationship of the physical features of the country to the life of man. The bulk of the text is devoted to description and analysis of the subdivisions or sections of the provinces, and this is, of course, the meat of the book for the geomorphologist. This analysis is much facilitated by topographic sketch maps modeled on the style of Lobeck. The introduction of short, more or less empiric descriptions of topography is a feature which will appeal to many readers. These descriptions are then expanded into "explanatory descriptions" in which the origin of the forms is set forth or the best available hypothesis is presented.

If one compares Fenneman's book with its predecessor, Bowman's *Forest Physiography* published in 1911, the obvious advance in American physiography lies in much higher precision of definition and in greater detailed representation of province and section boundaries. In some localities still smaller units have been discriminated as Gregory has done

for the Navajo Country. The discrimination of geomorphic units, however valuable, does not in itself, however, lead to more accurate and penetrating insight into the genesis of land forms. One notes in Fenneman's text a tendency to smooth over the difficulties and present a connected story. Bowman's less finished descriptions with their dependence on the original and earlier sources retain their value for the inquiring student. The footnote references of Fenneman do not repeat the nearly complete bibliographies of Bowman, but consist mostly of citations of the literature of the past twenty years. Some of these articles are given undue valuations and a few important papers are overlooked. Thus the description of the Lower California province (Peninsular ranges) fails to utilize the work of Ellis (*U.S. Geol. Surv. Water-Supply Paper 446*, 1921). The Bighorn Basin is described without reference to Hewett's monograph (*U.S. Geol. Surv. Prof. Paper 145*, 1926).

The specialist will note a naïve faith in the efficiency of wind work in areas where the evidence is slight, or for which erroneous criteria such as pedestal (mushroom) rocks are cited. These faults are, however, of minor importance. Fenneman has given a connected presentation of the state of knowledge of the varied topographic features of an enormous area. He has put this diverse material into a relatively small compass and produced a book suitable for use in teaching college classes. The very organization of the material shows the gaps in knowledge that should and will be filled by students whose first acquaintance with regional geomorphology will come through Fenneman's text.

KIRK BRYAN

The Geology of the Potosi and Edgehill Quadrangles. By C. L. DAKE. "Missouri Bureau of Geology and Mines," Vol. XXIII ([2d ser., 1930], 1931). Pp. 233; pls. 24; map.

This publication and the soon-to-be-issued companion volume by Josiah Bridge on the Eminence-Cardareva quadrangles are destined to form the point of departure for all future studies of one of the most complex and geologically important areas of the Interior Highlands. The present report has for its immediate "excuse" the demand for further information on the chief barite-producing area of the United States, but in actuality the region has many other features to recommend its study. The area is one of heavily wooded porphyry peaks, rugged sedimentary hills, and narrow water gaps, which the inhabitants colloquially call "shut-ins." The geologic problems include the igneous complex, the quaquaversal initial dips in sediments laid down over buried igneous hills, and

the great sequence of early Paleozoic formations, most of which are nearly or quite devoid of fossils, and many of which are embarassingly similar in general appearance. In addition there are other features, such as the pre-Cambrian and Paleozoic faulting, the isolated patches of the Pennsylvanian sediments which formerly almost completely covered the area, and the problems of the origin of the barite and lead. All of these subjects, and many others, are fully discussed in a report that is at once well written, fully illustrated, and nicely bound.

On the debit side there are only minor entries. A few typographical errors have, however, gotten by the proofreaders, the ubiquitous "none *are*" occasionally puts in its appearance, and some of the pictures apparently were taken with a none-too-level camera. Finally, the statements on page 184 that "There does not seem to be the slightest evidence of thrust faulting, here, or elsewhere in southeast Missouri," and that "Even the occurrence of slight overturn next to the fault plane, such as that reported by Weller and St. Clair is probably better explained as either extreme drag, or rotation of fragmented blocks between the fault walls, or between closely spaced minor faults," are not quite warranted. The reviewer is very familiar with the structural situation (in the Little Saline area of Ste Genevieve County) which Professor Weller "reported," and, although the case is by no means so clear cut as it might be, the evidence which is available is preponderantly in favor of thrust, not normal faulting.

CAREY CRONEIS

Elements of Engineering Geology. By H. RIES and T. L. WATSON. New York: John Wiley & Sons, Inc. 2d ed. Pp. 411; figs. 290. $3.75.

This book will fill a very useful place in engineering schools where a one-semester course in geology is thrust upon the "civils" and "mechanicals." It contains the essential information with a proper geologic background; indeed, if a person were to be limited to one book on geology in his library, this one would be an excellent choice. Practically the whole field of geology is covered and the portions most necessary to engineers are stressed.

With the ever increasing demand for control of natural processes, it is becoming more and more important for the engineer to have a working knowledge of geology. He may call in the geologist to supply detailed and technical information, but he must know how to interpret this and how to apply it to his problems. Skyscrapers and dams call for exact knowledge of the rocks supporting them; highways and railroads must be adapted to

the physiography of the region traversed; flood control and harbor engineering call for an understanding of the varying moods of nature. Tunneling, an operation of growing importance with the increasing demand for low grades on railroads, subways in big cities, and aqueducts to carry water supplies, call for an exact knowledge of the structures and types of rock which will be encountered. The geology of reservoirs and dam sites is stressed, with the St. Francis dam disaster as an example of negligence. Many other examples of good and of faulty dam- and reservoir-sites are discussed in sufficient detail to bring out the essential points.

Mining engineering is a highly specialized field, but almost any engineer may be called upon for work in a mine or with mining engineers, and the economic geology presented by the authors will be of much assistance in this connection. It will also be of service, perhaps not so directly, to all engineers who have to deal with mine products. The designing of smelters and refineries, of plants and machinery, can go on more intelligently if the designer knows something of the raw materials they are to handle.

Geologists should take more note of such books as this. If they understood the engineer's problems better and knew more of his "language," they could work in better harmony with him. Such a book contains much exact information, tersely presented, which is of great general usefulness; for instance, the definition of a *miners inch* and a *second foot* of water; the crushing strength of various rocks; the amount of load which can be safely borne by various rocks and unconsolidated sediments; hardness, toughness, and cementing values of various rocks.

J. T. McC.

Chemische Bodenanalyse. By K. K. GEDROIZ. Berlin: Gebrüder Borntraeger, 1926. Rm. 12.

This textbook on soil analysis was recently published in Russian, and has been translated from the Russian into German by L. Frye. Its first chapter is the preparation of the soil for analysis. The second chapter discusses the methods of a preliminary analysis. The third chapter describes the determination of lithium, rubidium, caesium, titanium, zirconium, and vanadium. Chapters iv–ix deal with various methods of examining extractions from soils with colorimetric determinations and the determination of the lime needed by plants in soils. The tenth chapter tells about the most important reagents.

A. C. NOÉ